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Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway Remedial Investigation

FOOD WEB MODEL MEMORANDUM 3
PRELIMINARY MODEL RESULTS

For submittal to

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

April 7, 2006

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List of Acronyms

Acronym	Definition
DOC	dissolved organic carbon
dw	dry weight
Ecology	Washington State Department of Ecology
EFDC	Environmental Fluid Dynamics Computer Code
EPA	US Environmental Protection Agency
ERA	ecological risk assessment
FS	feasibility study
FWM	food web model
HHRA	human health risk assessment
K_{OW}	octanol-water partition coefficient
LDW	Lower Duwamish Waterway
NLOM	non-lipid organic matter

Acronym	Definition
OC_{sed}	organic carbon concentrations in sediment
PCB	polychlorinated biphenyl
POC	particulate organic carbon
QAPP	quality assurance project plan
RBG	risk-based goal
RI	remedial investigation
RM	river mile
SPAF	species predictive accuracy factor
SPD	species percent difference
SQT	sediment quality threshold
SWAC	spatially weighted average concentration
ww	wet weight

1.0 Introduction

A comprehensive dataset of chemical concentrations in sediment and tissue samples has been collected in the Lower Duwamish Waterway (LDW) to define the nature and extent of contamination and to conduct baseline risk assessments for the LDW Phase 2 remedial investigation (RI). These data will also be used to support a food web model (FWM) for the LDW based on the model of Arnot and Gobas (Arnot and Gobas 2004). The FWM is needed for two applications. As part of the RI, risk-based goals (RBGs) for fish and crab tissue[1] will be established based on the results of the ecological and human health risk assessments (ERA and HHRA), and those tissue RBGs will be translated into sediment quality thresholds (SQTs)[2] using the FWM. In the feasibility study (FS), the FWM will also be used as one tool to evaluate residual risks associated with various sediment cleanup alternatives.

Three memoranda that describe the FWM have been prepared to present a rationale for the selection of a model, the modeling approach, and the results of preliminary modeling runs. This document is the third of these three FWM memoranda and focuses on the results of preliminary model runs. The final documentation and application of the FWM will be presented in the Phase 2 RI.

The purpose of this memorandum is to present preliminary results of the FWM to further elucidate model assumptions and sensitivities. The Arnot and Gobas-based FWM (Arnot and Gobas 2004) is being used to estimate the uptake of total PCBs from sediment and water through the food chain for five target species (slender and Dungeness crabs, English sole, shiner surfperch, and Pacific staghorn sculpin). In addition, concentrations of PCBs in the tissues of four other groups of organisms (phytoplankton, zooplankton, benthic invertebrates, and juvenile fish) that are prey for the target species are also predicted. Collectively, the target species and the prey species are referred to as the modeled species. Empirical PCB tissue concentration data in the LDW exist for benthic invertebrates, slender crabs, Dungeness crabs, Pacific staghorn sculpin, shiner surfperch, and English sole. The other modeled species have no empirical PCB tissue concentration data. Total PCB concentrations are being predicted in tissue for these nine categories of fish and invertebrates within the entire LDW and, for some species, within smaller areas of the LDW. Following the identification of input parameter values and data (Section 2), preliminary model runs and analyses that were carried out to evaluate the model's overall performance are:

[1] Clam RBGs will be developed in the HHRA. The clam RBGs will then be translated into SQTs using biota-sediment accumulation factors.

[2] SQTs are chemical concentrations in sediment associated with specific acceptable risk estimates. SQTs may be derived for a variety of exposure scenarios.

- **LDW-wide model run.** The FWM was run at the LDW-wide (i.e., site-wide) spatial scale, and the performance of the FWM was evaluated relative to empirical data. Methods and results are discussed in Section 3.0.
- **Dietary scenarios.** The FWM was run with several dietary scenarios to assess the sensitivity and model performance. Methods and results are discussed in Section 4.0.
- **Sensitivity analyses.** Sensitivity analyses were conducted at the LDW-wide spatial scale to determine: a) parameters to which the FWM is most sensitive, and b) how sensitive the model is to the plausible ranges of certain parameter values. The FWM was also run with a range of total PCB water column concentrations to test model performance within that range, and to conduct a preliminary investigation into the sensitivity of the FWM to total PCB concentrations in water. This analysis was conducted to provide additional information to decide whether additional water column data should be collected this summer. Methods and results are discussed in Section 5.0.
- **Uncertainty analysis.** An uncertainty analysis was conducted at the LDW-wide spatial scale to characterize the combined effect of the uncertainty associated with each input parameter. Methods and results are discussed in Section 6.0.
- **Smaller spatial scale model runs.** The FWM was run at a smaller spatial scale (referred to as modeling areas) for all modeled species. Methods and results are discussed in Section 7.0.

Based on the preliminary results, several parameters and assumptions were identified for further consideration during calibration of the FWM. These parameters and assumptions are discussed in Section 8.0. The steps to finalize the FWM after the submittal of this memorandum are presented in Section 9.0.

The results presented in this memorandum and the results that will be presented in the Phase 2 RI are likely to be different for three reasons. First, some of the key input parameters to the FWM are still being developed. For example, the concentration of polychlorinated biphenyls (PCBs) in sediment is being determined through interpolation of the baseline surface sediment dataset. Both the baseline dataset and the interpolation methodology are being discussed with the US Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology) at this time. Second, the concentrations of PCBs in water will ultimately be provided by King County based on output from the Environmental Fluid Dynamics Computer Code (EFDC) hydrodynamic model. Further calibration of this model is ongoing this spring to incorporate water and sediment data collected over the past year. Third, the FWM will likely be calibrated prior to its application in the Phase 2 RI. Refinements to the calibration will be based on the results of the preliminary sensitivity/uncertainty analyses and the dietary scenarios presented in this memorandum as well as updated sediment and water inputs, as discussed above. The purpose of calibration, which will be conducted in consultation with EPA and Ecology, is to achieve the best fit using empirical data from the LDW, while remaining within reasonable assumptions for key input parameters. The overall process that will be followed prior to the presentation of the FWM results in the Phase 2 RI is presented in this memorandum (Section 9), and will also be discussed with stakeholders.

2.0 Selection of Parameter Values

The Gobas and Arnot (2004) model requires input values for 36 parameters to predict concentrations of hydrophobic chemicals in aquatic organisms. Some parameters are species-specific and thus require more than one value. This section and Appendix A present the initial values selected for the FWM. As discussed in the FWM Memorandum 2 (Windward 2005b), these initial values form the basis for preliminary model runs and preliminary uncertainty and sensitivity analyses. If needed to meet the model performance goal (i.e., predictions within a factor of 3 of empirical data), these initial parameter values will be modified in consultation with EPA and Ecology prior to their final application in the Phase 2 RI.

For this memorandum, the FWM is being used to predict the total PCB concentrations[3] in the tissues of the five target species (slender and Dungeness crabs, English sole, shiner surfperch, and Pacific staghorn sculpin) in the LDW. In addition, PCB concentrations in the tissue of four species groups (phytoplankton, zooplankton, benthic invertebrates, and juvenile fish) are being predicted by the model as prey for the target species. Each species has its own set of parameter values to define its biological state (e.g., lipid content, water content, and weight[4]) and diet. The same values for environmental parameters that define the chemical and physical conditions of the LDW (e.g., water temperature, oxygen concentration) are being used for each species. Chemical-specific parameter values (e.g., K_{OW}) are also required for the chemical being modeled (e.g., total PCBs). Because total PCBs include a mixture of individual PCBs congeners, parameters such as K_{OW} were estimated from available PCB congener data (see Section A.3 in Appendix A)

Values for each of the FWM parameters appropriate for the LDW were selected from three major source categories: site-specific data, literature data, or default values used or cited in Arnot and Gobas (2004) or in a San Francisco Bay application of the same model

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[3] As discussed in the second deliverable, the FWM may later be used to predict concentrations of other chemicals if these chemicals are found to be risk drivers.

[4] Weight is calculated in several different ways (e.g., average of individual LDW samples or literature-based). For fish and crabs, the weight represents the average adult weight of that species in the LDW. For zooplankton, it represents an average weight of all zooplankton captured in a Puget Sound inlet over a year period. Thus, the value chosen for the weight zooplankton parameter does not necessarily represent realistic expected size ranges that are actually consumed by target species in the LDW, but was chosen from values available in the literature for the region.

(Gobas and Arnot 2005). Values for six species-specific parameters, including organism weight, lipid content, non-lipid organic matter content, water content, diets, and fraction of pore water and overlying water ventilated, were derived from either LDW or literature data (Appendix A, Table A-5-1). Values for eight parameters, including total PCB and organic carbon concentrations in sediment (OC_{sed}), total PCB concentration in water, and five water quality parameters, were derived from LDW data (Appendix A, Table A-2-1). Two chemical-specific parameters, including K_{OW} and Henry's Law Constant, were determined from the literature (Appendix A, Table A-3-1). Twenty parameter values were default values, as cited in Arnot and Gobas (2004) or Gobas and Arnot (2005). The majority of parameters with default values are constants in the model equations, except for the rate constant for metabolic transformation of PCBs and the density of lipids and water (Appendix A, Table A-4-1). The initial set of input parameter values used in the analyses reported here was determined for the LDW as a whole. Different parameter values may be used in later modeling of smaller areas of the LDW. Parameter names, symbols, units, selected values, comments, and source information for the initial set of input values are presented in Appendix A.

Modeled species diets are restricted to the compartments selected for the FWM. Each compartment is a surrogate dietary item for the organisms consumed by modeled species. As specified in FWM Memorandum 1, these dietary surrogates include sediment, phytoplankton, zooplankton, benthic invertebrates, and small prey fish (Windward 2005a). For all model runs other than those exploring various dietary scenarios, the proportions of each dietary surrogate in modeled species diets are those specified in dietary scenario 1, which is one of several plausible dietary scenarios investigated (Section 4.0).

Input parameter values were derived for the LDW at two spatial scales: the LDW-wide spatial scale and the modeling area spatial scale (Figure 2-1).[5] Modeling areas (Areas M1 to M4) were defined as fish and crab tissue sampling areas extended out to the center point between tissue sampling areas. At the modeling area scale, the FWM was run separately for each modeling area. All species were modeled at both spatial scales. Parameter values that were changed with scale included the total PCB and OC_{sed} concentrations in sediment, fish and invertebrate lipid and water contents, and fish and crab weights. When output data for total PCB concentrations in water are available from EFDC, this input parameter will also be based on the specific modeling areas.

[5] The LDW-wide spatial scale was defined as River Mile (RM) 0 to RM 5.0. Modeling areas were as follows: M1 (RM 0.0 to RM 1.3), M2 (RM 1.3 to RM 2.65), M3 (RM 2.65 to RM 3.95), and M4 (RM 3.95 to RM 5.0).

Figure 2-1. Lower Duwamish Waterway modeling areas

Prepared by STS 04/07/06 Map 2109

W:\Projects\00-08-06_Duwamish_RI\data\gis\Tissue Chemistry\Tissue Area Polygons

In addition to the LDW-wide and modeling area scales, shiner surfperch and Pacific staghorn sculpin will also be modeled in the future at the subarea scale, which is smaller than the modeling area (Figure 2-1). These two target species will be evaluated at this scale because it is possible that the foraging range for these species may be smaller than a modeling area, although the sizes of their foraging ranges are uncertain.[6] Unlike the other targeted species (i.e., slender and Dungeness crabs, English sole), for which composite tissue samples were available only for entire tissue sampling areas, Phase 2 tissue data are available for shiner surfperch and Pacific staghorn sculpin from each of the tissue sampling subareas shown in Figure 2-1. Thus, FWM predictions can be compared to empirical data for the latter species at this scale. This subarea scale was not investigated for this memorandum because total PCB concentrations in water were not yet available at a subarea scale. The total PCB concentrations in water will be generated by the EFDC model following recalibration with an updated sediment and water data. EFDC predictions of PCB water concentrations at smaller spatial scales will be available in the spring of 2006.

When the water data are available, a subset of the tissue sampling subareas will be modeled for shiner surfperch and Pacific staghorn sculpin. Subareas T1-B, T1-E, T2-B, T2-E, T3-B, T3-F, T4-A, and T4-D have been selected for modeling because they provide spatial coverage of the LDW and represent a range of total PCB concentrations in tissue and sediment (Figure 2-2).

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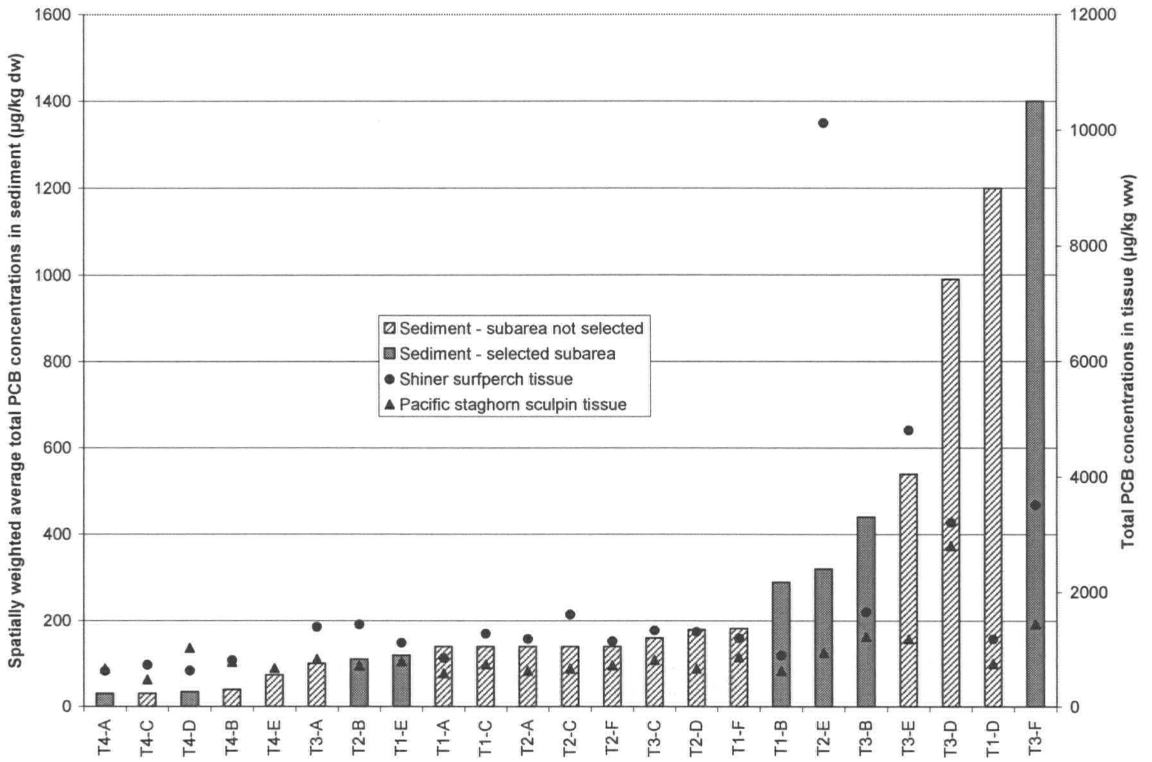
[6] Local fish experts expressed opinions at a March 31, 2004, meeting that foraging movements for target species may be as large as the LDW or as small as a tissue subarea.

Figure 2-2. Total PCB concentrations in tissue sampling subareas



Parameter values that will differ between the modeling area and the subarea spatial scales will include total PCB concentrations in sediment and water as well as OC_{sed} concentrations in sediment. Fish weight, lipid, and water content data from the corresponding modeling area will be used at a subarea scale because these parameters are not expected to vary among fish sampling subareas within the corresponding modeling area. Predicted shiner surfperch and Pacific staghorn sculpin total PCB tissue concentrations from a given subarea model will be compared to empirical data from the corresponding subarea.

3.0 Application of the FWM at the LDW-Wide Scale

The FWM was run at the LDW-wide spatial scale to test the model's ability to predict total PCB concentrations in tissue for the target species being modeled. The LDW-wide spatial scale integrates the exposure of modeled species throughout the LDW regardless of foraging ranges. Application of the FWM to smaller spatial scales is discussed in Sections 7.0 and 8.0.

3.1 METHODS

Preliminary runs of the FWM were conducted with the initial set of input parameter values presented in Appendix A (Tables A-1-2, A-2-1, A-2-2, A-2-3, A-3-1, and A-4-1). The initial set of input parameter values included dietary scenario 1, which is one of several plausible dietary scenarios investigated (Section 4.0). Predicted total PCB tissue concentrations were compared to available empirical data for five fish and crab species using two model performance metrics, the species predictive accuracy factor (SPAF), which was discussed in detail in FWM Memorandum 2 (Windward 2005b), and the percent difference metric. Below are equations describing the SPAF and percent difference metrics.

The species predictive accuracy factor (SPAF) is the ratio of predicted to empirical tissue chemical concentrations. If predicted tissue chemical concentrations were higher than empirical tissue chemical concentrations, then Equation 3-1 was used to calculate the SPAF:

$$\mathrm{SPAF} = \frac{\mathrm{PTCC}}{\mathrm{ETCC}} \qquad \textbf{Equation 3-1}$$

where:

PTCC = predicted tissue chemical concentration
ETCC = empirical tissue chemical concentration

If predicted tissue chemical concentrations were lower than empirical tissue chemical concentrations, then Equation 3-2 was used to calculate the SPAF:

$$\mathrm{SPAF} = \frac{\mathrm{ETCC}}{\mathrm{PTCC}} \qquad \textbf{Equation 3-2}$$

The percent difference is a model performance metric that measures the difference of the predicted and empirical tissue chemical concentration relative to the magnitude of the empirical tissue chemical concentration. It is calculated as follows:

$$\%\ \text{difference} = \frac{\text{PTCC} - \text{ETCC}}{\text{ETCC}} \qquad \textbf{Equation 3-3}$$

Three empirical datasets are available for comparison to predicted results (Table 3-1). Two of these datasets were collected as part of the Phase 2 RI (fish and crab tissue samples were collected in 2004 and 2005). The third dataset combines data from numerous studies conducted since 1990 (these data are referred to as historical data). Total PCB concentrations in the 2004 Phase 2 fish and crab samples were generally higher than those in historical samples or the 2005 Phase 2 fish and crab samples (Table 3-1). In this memorandum, the results of the FWM are generally compared to mean total PCB concentrations from all three datasets combined to simplify the presentation of results. To assess the performance of the model relative to specific datasets, model runs are also compared to total PCB concentrations for historical and Phase 2 (2004 and 2005) data separately for the LDW-wide results in Section 3-2. The empirical tissue data used in these comparisons are discussed further in Appendix A, Section A.2.3. The dataset(s) to be used to calibrate the FWM will be discussed with EPA and Ecology prior to calibration, as discussed in Section 8.0.

Predicted total PCB concentrations in benthic invertebrate tissues were not compared directly to empirical data. As described in the quality assurance project plan (QAPP) for the collection and analysis of benthic invertebrate tissue (Windward 2004), locations for benthic invertebrate tissue sampling were selected to provide good spatial coverage and to represent the full range of total PCB concentrations in sediment. The sampling locations were not selected to provide a representative sample of total PCB tissue concentrations in the benthic invertebrate community throughout the LDW. A tissue-sediment regression was derived from the co-located sediment and benthic invertebrate tissue data (Appendix A), and used to estimate the most appropriate site-specific total PCB tissue concentration for comparison to values predicted by the FWM. The resulting regression equation was then applied to the spatially weighted average concentration (SWAC) of total PCBs in sediment to estimate a representative site-wide total PCB concentration in benthic invertebrate tissues. Details of this approach are presented in Section A.2.4 of Appendix A. SWAC values used both for the LDW-wide model runs as well as the modeling-area-scale runs were based on preliminary IDW interpolations. Subsequent IDW interpolations are likely to result in different values that will be used in the FWM applications for the RI/FS.

Table 3-1. Available empirical total PCB data for target species from LDW tissue sampling areas

Species	Tissue Type	Location	Historical					Phase 2 (2004)					Phase 2 (2005)				
			N	No. per Composite	Total PCBs (µg/kg ww)			N	No. per Composite	Total PCBs (µg/kg ww)			N	No. per Composite	Total PCBs (µg/kg ww)		
					Min	Max	Avg			Min	Max	Avg			Min	Max	Avg
Dungeness crab	Whole-body[a]	T1	1	3	640	640	640	1	15[b]	1,400	1,400	1,400	1	5[b]	450	450	450
		T2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
		T3	nd	nd	nd	nd	nd	1	15[b]	1,600	1,600	1,600	1	5[b]	420	420	420
		T4	nd	nd	nd	nd	nd	1	6[b]	1,900	1,900	1,900	1	5[b]	420	420	420
		LDW-wide	1	3	640	640	640	3	6 – 15[b]	1,400	1,900	1,600	3	5[b]	420	450	430
Slender crab	Whole-body[a]	T1	nd	nd	nd	nd	nd	1	16[b]	650	650	650	nd	nd	nd	nd	nd
		T2	nd	nd	nd	nd	nd	2	15[b]	750	800	780	1	10[b]	250	250	250
		T3	nd	nd	nd	nd	nd	1	18[b]	630	630	630	nd	nd	nd	nd	nd
		T4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
		LDW-wide	nd	nd	nd	nd	nd	4	15 – 18[b]	630	800	710	1	10[b]	250	250	250
Shiner surfperch	Whole-body	T1	3	10	350	620	500	6	9 – 10	970	1,830	1,400	6	10	530	960	780
		T2	nd	nd	nd	nd	nd	6	9 – 10	1,260	18,400	4,300	6	10	660	2,000	1,300
		T3	2	1	940	2,100	1,500	6	10	1,280	8,800	3,800	6	10	700	2,400	1,500
		T4	nd	nd	nd	nd	nd	6	10	640	960	800	4	10	540	600	580
		LDW-wide	5	1 – 10	350	2,100	900	24	9 – 10	640	18,400	2,600	22	10	530	2,400	1,100
English sole	Whole-body	T1	nd	nd	nd	nd	nd	6	5	2,700	4,700	3,700	6[c]	5	1,120	2,200	1,600
		T2	nd	nd	nd	nd	nd	6	5	3,300	4,200	3,900	6[c]	5	1,600	2,400	2,000
		T3	nd	nd	nd	nd	nd	6	5	1,320	4,300	2,600	6[c]	5	610	2,200	1,400
		T4	nd	nd	nd	nd	nd	3	5	1,640	1,800	1,700	3[c]	5	910	1,180	1,000
		LDW-wide	nd	nd	nd	nd	nd	21	5	1,320	4,700	3,200	21[c]	5	610	2,400	1,600

Species	Tissue Type	Location	Historical N	Historical No. per Composite	Historical Total PCBs (µg/kg ww) Min	Max	Avg	Phase 2 (2004) N	Phase 2 (2004) No. per Composite	Phase 2 (2004) Total PCBs (µg/kg ww) Min	Max	Avg	Phase 2 (2005) N	Phase 2 (2005) No. per Composite	Phase 2 (2005) Total PCBs (µg/kg ww) Min	Max	Avg
Pacific staghorn sculpin	Whole-body	T1	nd	nd	nd	nd	nd	6	10	580	860	730	1	10	720	720	720
		T2	nd	nd	nd	nd	nd	6	7 – 10	620	1,260	770	1	10	620	620	620
		T3	nd	nd	nd	nd	nd	6	10	810	2,800	1,500	1	10	590	590	590
		T4	nd	nd	nd	nd	nd	6	8 – 10	510	1,300	780	1	10	430	430	430
		LDW-wide	nd	nd	nd	nd	nd	24	7 – 10	510	2,800	950	4	10	430	720	590

[a] Each whole-body crab total PCB concentration was estimated by combining the total PCB concentration in the composite hepatopancreas sample with the total PCB concentration in the corresponding edible meat composite samples (one or more samples) that were collected from the same crabs. Therefore, a single whole-body crab total PCB concentration was calculated for each composite hepatopancreas sample. Whole-body total PCB concentrations were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004.

[b] This number of crabs per composite sample represents the number of hepatopancreas samples per whole-body calculated composite sample. The number of edible meat samples ranged from five to fifteen per whole-body calculated composite sample.

[c] One half of the samples from each tissue sampling area were calculated as the weighted average of fillet and remainder composite samples collected for comparison between fillet and whole-body total PCB concentrations, as specified in the quality assurance project plan (QAPP) (Windward 2005c) and the data report (Windward 2006 in prep).

N – Number of composite samples

nd – no data

No empirical tissue data are available for phytoplankton, zooplankton, or juvenile fish. Concentrations of PCBs in tissues of these organism groups were modeled to estimate dietary concentrations for other modeled species.

3.2 Results

The total PCB concentrations in all modeled target species were predicted within a factor of 3.2 of empirical data (Table 3-2). As discussed in FWM deliverable 2, for the initial calibration, a performance criterion of predictions "within a factor of 5 of empirical data" (< 5 and > -5 for all SPAFs) was presented. A model performance criterion of "within a factor of 5" for all species was set for Gobas models on the Fox River (ThermoRetec 2001) and Hudson River (TAMS 2000). The goal for the final calibration phase was established as "within a factor of 3" of empirical tissue data. A model parameterization that at least meets the model performance criterion (i.e., within a factor of 5) will be used in the RI/FS.

Thus, the model performance criterion of "within a factor of 5 of empirical data" was met in the preliminary runs of the FWM at the scale of the entire waterway. Furthermore, the model performance goal of "within a factor of 3," outlined in FWM Memorandum 2 was met for all species but one (i.e., Pacific staghorn sculpin). Despite these initial successes, additional steps will be taken with the FWM to further refine predictions at the LDW-wide or smaller scale. These steps are discussed in Sections 8.0 and 9.0.

Table 3-2. Preliminary model run results for the LDW-wide scale compared to mean empirical total PCB concentrations (all datasets combined)

Species	Mean Empirical Total PCB Concentration (µg/kg ww)[a]	Model-Predicted Total PCB Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	170[d]	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+

SPECIES	MEAN EMPIRICAL TOTAL PCB CONCENTRATION (µg/kg ww)[a]	MODEL-PREDICTED TOTAL PCB CONCENTRATION (µg/kg ww)	% DIFFERENCE[b]	SPECIES PREDICTIVE ACCURACY FACTOR[c]	OVERPREDICTION (+) OR UNDERPREDICTION (-)
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	

[a] Mean empirical data are represented by an average of all three empirical datasets over all LDW tissue samples for a given species. Data are discussed further in Appendix A, Section A.2.3.

[b] The percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[c] The species predictive accuracy factor (or SPAF) is the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

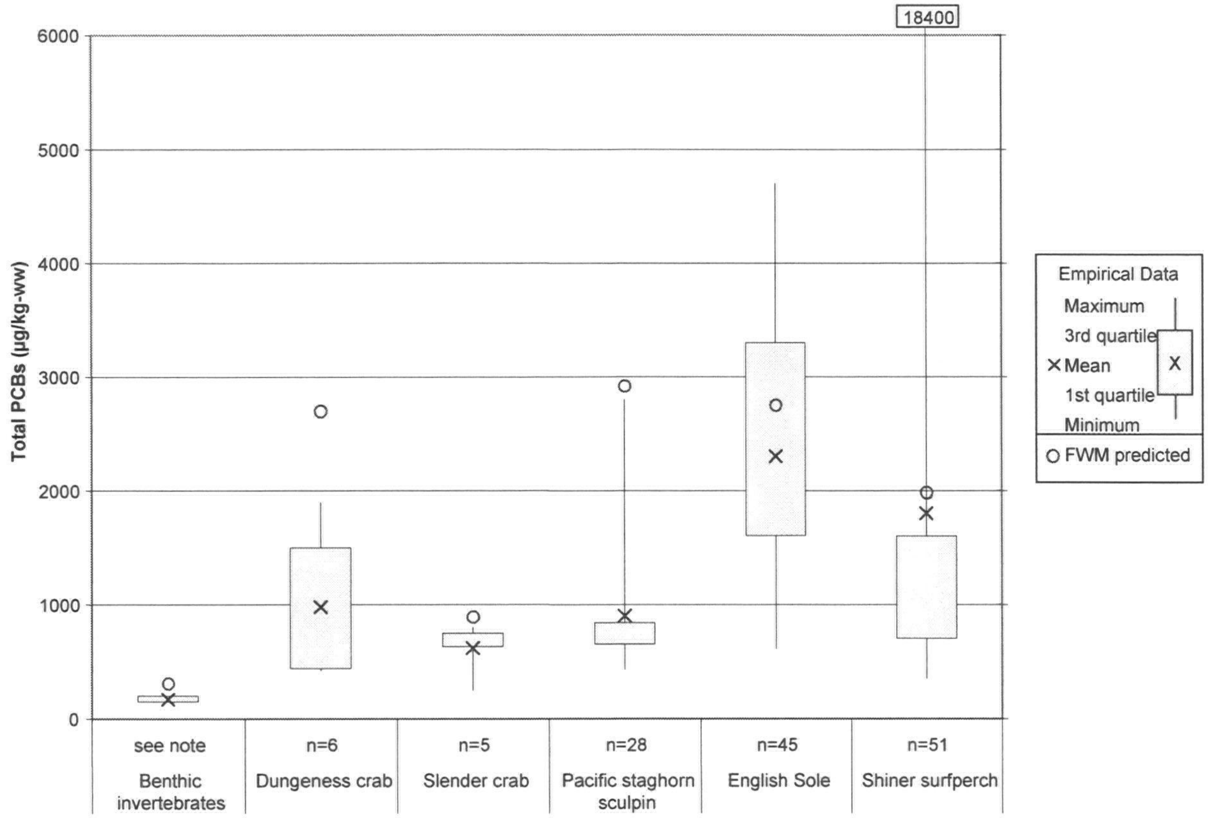
[d] Concentration predicted from sediment-tissue total PCB regression at an LDW-wide total PCB SWAC of 250 µg/kg dw.

na – not applicable

nd – no data

All predicted concentrations were greater than the mean empirical data (all datasets combined) for each species (Figure 3-1). Thus, based on the initial set of parameters, the FWM is consistently over-predicting by varying degrees or the LDW-wide scale. Predictions for shiner surfperch, English sole, and slender crab were within a factor of 1.5 of empirical data. Implications of using different datasets are discussed in Section 8.0.

Figure 3-1. Preliminary model run results for the LDW-wide scale compared to empirical total PCB concentrations (all datasets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

Preliminary FWM results were also compared to the 2004 and 2005 datasets separately because the total PCB concentrations in tissue were consistently lower in 2005 than in 2004 (Tables 3-1 and 3-3 and Figure 3-2). The model performance when compared to the 2004 dataset was generally similar to that for all datasets combined, although some species (shiner surfperch and English sole) were slightly underpredicted rather than slightly overpredicted. The model performance when compared to the 2005 dataset is similar to that for the combined datasets for shiner surfperch and English sole. However, the model-predicted total PCB concentrations for slender crab, Dungeness crab, and Pacific staghorn sculpin were much higher than the empirical data from 2005 (with SPAFs ranging from 3.6 to 6.3). Implications of using different datasets are discussed in Section 8.0.

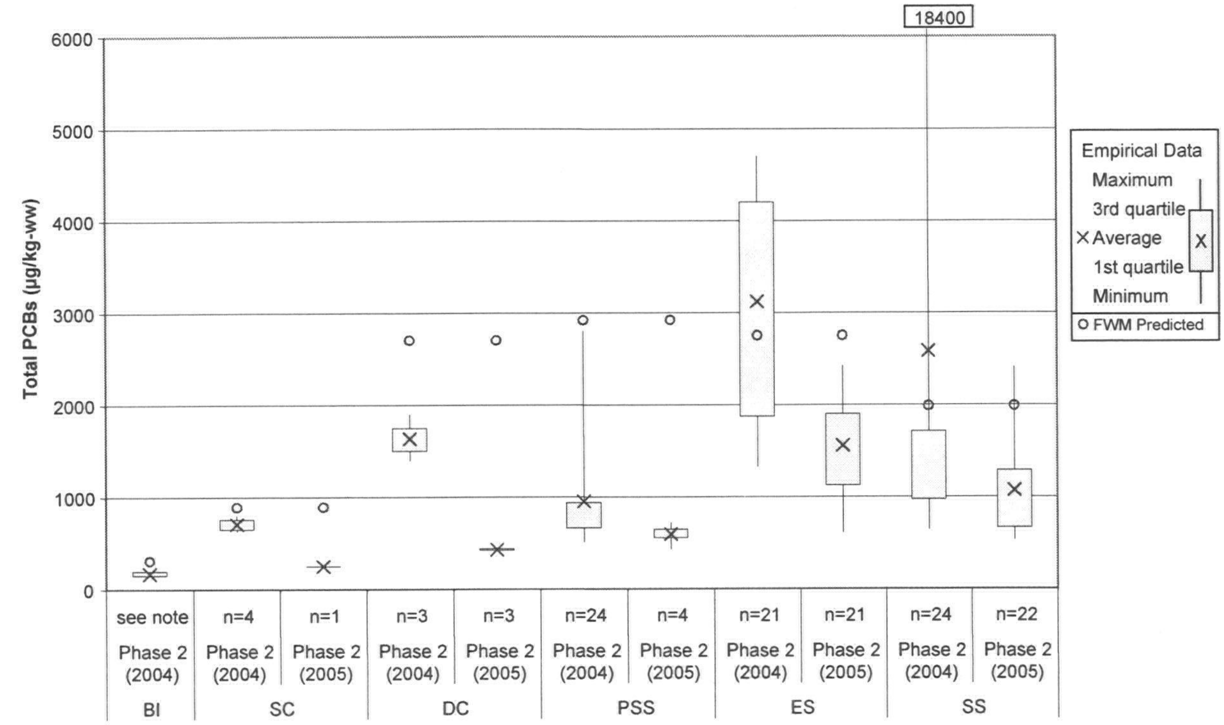
Table 3-3. **Preliminary fish and crab model run results for the LDW-wide scale compared to 2004 and 2005 mean empirical total PCB concentrations**

Species	Phase 2 (2004) Empirical Total PCB Concentration (µg/kg ww)	Phase 2 (2005) Empirical Total PCB Concentration (µg/kg ww)	Model-Predicted Total PCB Concentration (µg/kg ww)	2004 Data			2005 Data		
				% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) Underprediction (-)	% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) or Underprediction (-)
Slender crab	710	250	893	26%	1.3	+	257%	3.6	+
Dungeness crab	1,600	430	2,705	69%	1.7	+	529%	6.3	+
Pacific staghorn sculpin	950	590	2,921	207%	3.1	+	395%	5.0	+
Shiner surfperch	2,600	1,100	1,986	-24%	1.3	-	81%	1.8	+
English sole	3,100	1,600	2,752	-11%	1.1	-	72%	1.7	+
All Species									
Mean				53%	1.7		267%	3.7	
Maximum				207%	3.1		529%	6.3	
Minimum				-11%	1.1		72%	1.7	

a The percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

b The SPAF is the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

Figure 3-2. Preliminary model run results for the LDW-wide scale compared to Phase 2 (2004 and 2005) empirical total PCB concentrations



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

BI – benthic invertebrates

SC – slender crab

DC – Dungeness crab

PSS – Pacific staghorn sculpin

ES – English sole

SS – shiner surfperch

4.0 Dietary Scenarios

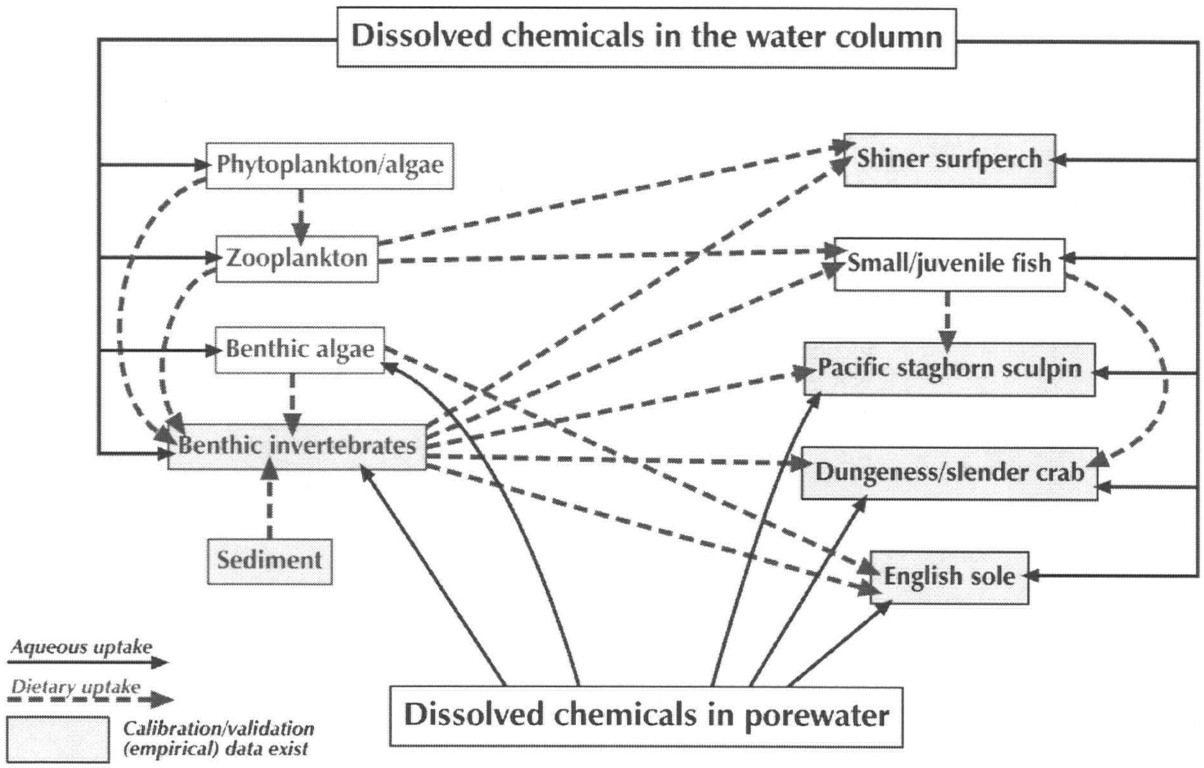
Up to four plausible dietary scenarios for each target species were used as model inputs on an LDW-wide scale. Different dietary scenarios were input because there is uncertainty regarding the diets of the species being modeled and because dietary assumptions can be important in model performance. The results of these preliminary model runs will be assessed, in consultation with EPA and Ecology, to select a dietary scenario for use in the model runs for the Phase 2 RI (see Sections 8.0 and 9.0).

Diets of fish and crabs are difficult to characterize because they vary by location, season, age, and size class. Diets are also difficult to quantify in terms of mass or volume fractions because stomach content analyses favor items that are digested more slowly. In addition, certain feeding habits, such as scavenging, or extensive mastication of the food items, makes food-item species identification difficult.

Thus, simplifying assumptions must be made when estimating diets because ecosystems are complex and dynamic environments that cannot be fully characterized in a quantitative manner without a high level of uncertainty. Simplified food web models and dietary assumptions were developed for the three fish species and two crab species (Figure 4-1 as an example). Various boxes or "compartments" are included in the dietary scenarios, each representing a group of species or abiotic media that may influence chemical transfer and bioaccumulation.

Ecology, behavior, feeding observation studies, stomach content analyses were considered in the creation of the simplified uptake routes and plausible dietary scenarios developed to reflect average diets. These scenarios are discussed in this section (see Appendix A, Section A.3.1).

Figure 4-1. Simplified dietary and aqueous uptake routes for LDW biota (dietary scenario 1 as an example)



4.1 METHODS

Dietary items of the modeled species are restricted to the model compartments (e.g., benthic invertebrates, sediment) selected for the FWM. Each compartment modeled may be used as a surrogate dietary item for the items actually consumed by modeled species. It should be noted, however, that a given modeled species cannot have a fraction of its diet from its own model compartment (e.g., benthic invertebrates are not allowed to consume benthic invertebrates if there is only one benthic invertebrate compartment). This is a limitation of the current version of the model, which is in Excel®. In addition to compartments for target species, model compartments representing dietary components include sediment, phytoplankton, zooplankton, benthic invertebrates, and juvenile fish, as specified in FWM Memorandum 1 (Windward 2005a). In some cases, where a tissue type reported in the literature to be consumed by a modeled species is lacking in the LDW database, the surrogate tissue was selected. For example, Pacific staghorn sculpin are expected to eat shrimp, but measured or estimated concentrations in shrimp are not available, so the fraction of shrimp in the sculpin diet was substituted with estimates of PCBs in either benthic invertebrate tissue (dietary scenario 1) or in zooplankton (dietary scenario 2).

Four different dietary scenarios were modeled. The FWM was run with the initial set of input values held constant while dietary assumptions were changed for each scenario run.

4.1.1 Fish and crab dietary scenarios

Four dietary scenarios are presented for the fish and crab species modeled (Table 4-1. Appendix Table A-2-3). In general, dietary scenarios 1 and 2 were statistical estimates of the organisms' diets based on stomach content analyses presented in the literature. Dietary scenario 2 was the same as dietary scenario 1, except that crab or shrimp prey items in the dietary studies were represented by the zooplankton compartment instead of the benthic invertebrates compartment. A surrogate prey item was needed for juvenile crabs and shrimp because they are not included as a model compartment in the simplified food web developed for the LDW, primarily because no data were available for these species/life stages in the LDW. Zooplankton are a reasonable surrogate because zooplankton, juvenile crabs, and especially shrimp are primarily exposed to PCBs in the water column versus other benthic invertebrates that receive most of their exposure through association with sediment. All target fish and crab species are opportunistic feeders and may consume juvenile crab and/or shrimp to some extent. Dietary scenario 3 was created from studies that considered organism ecology and behavior in addition to the literature presenting stomach content analyses. Dietary scenario 3 was the only scenario that included sediment as a fraction of the diet, and all fish and crab species were therefore assumed to consume 10% sediment by weight for this scenario. Dungeness crabs were the only species with a fourth dietary scenario. This scenario was based on an additional literature source that quantified stomach contents using a different metric (Gotshall 1977).

Table 4-1. Fraction of dietary surrogates consumed by modeled fish and crab species in the four dietary scenarios investigated

Species	Dietary Surrogate	Fraction of Diet by Scenario[a]				Sources
		Scenario 1[b,c]	Scenario 2[b,d]	Scenario 3[e]	Scenario 4[c]	
Dungeness crab	zooplankton	0	0.48	0	0	Stevens et al. (1982) for scenarios 1 and 2; Gotshall (1977) for scenario 4
	benthic invertebrates	0.63	0.16	0.75	0.75	
	juvenile fish	0.37	0.36	0.15	0.25	
	sediment	0	0	0.10	0	
	total	1.0	1.0	1.0	1.0	
Slender crab	zooplankton	0	0.12	0	na	Bernard (1979)
	benthic invertebrates	0.99	0.87	0.90	na	
	juvenile fish	0.01	0.01	0	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
Juvenile fish	zooplankton	0.07	0.17	0.05	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.93	0.83	0.85	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
Shiner surfperch	zooplankton	0.14	0.21	0.10	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.86	0.79	0.80	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	
English sole	phytoplankton/ algae	0.08	0.07	0	na	Fresh et al. (1979); Wingert et al. (1979)
	zooplankton	0	0.05	0	na	
	benthic invertebrates	0.92	0.88	0.90	na	
	sediment	0	0	0.10	na	
	total	1.0	1.0	1.0	na	

Species	Dietary Surrogate	Fraction of Diet by Scenario[a]				Sources
		Scenario 1[b,c]	Scenario 2[b,d]	Scenario 3[e]	Scenario 4[c]	
Pacific staghorn sculpin	zooplankton	0	0.37	0.25	na	Fresh et al. (1979); Miller et al. (1977); Wingert et al. (1979)
	benthic invertebrates	0.56	0.19	0.50	na	
	fish	0.44	0.44	0.15	na	
	sediment	0	0	0.10	0	
	total	1.0	1.0	1.0	na	

a Average over all studies.

b Unidentifiable prey items excluded from calculation.

c Crab and shrimp prey were assigned to the benthic invertebrate compartment.

d Crab and shrimp prey were assigned to the zooplankton compartment.

e Integration of available data; 10% sediment consumption was assumed. For Pacific staghorn sculpin, crab and shrimp prey were assigned to the zooplankton compartment.

na – not available; no scenario investigated

4.1.2 Benthic invertebrate dietary scenarios

Benthic invertebrate communities in the LDW are composed of many species from many phyla within multiple feeding guilds. Dominant feeding guilds for each taxon were assigned using the literature. Assigned feeding guilds included deposit feeders (including detritivores), suspension feeders, and carnivores. Feeding guilds were assigned to each phylum (LDW subtidal samples only), and then the percent of each sample represented by each feeding guild was determined based on the percent by weight that each phylum represented of the total. Average percent feeding guilds were calculated for all 10 LDW subtidal benthic samples. Because the FWM does not allow modeled species to eat tissue within the same compartment (i.e., have a fraction of their diet from their own model compartment), and only one benthic invertebrate compartment was created, sediment was used as a surrogate for benthic invertebrate prey consumed by carnivores. A "detritus" compartment was not modeled because there were insufficient data to generate values for such a compartment. Sediment was used as a surrogate for detritus consumed by deposit feeders. Dietary scenario 1 was constructed assuming that carnivores consumed 100% sediment, suspension feeders consumed 30% zooplankton and 70% phytoplankton/algae, and deposit feeders consumed 100% sediment. For a more detailed description of methods used to generate dietary scenarios for benthic invertebrates, see Appendix A, Section A.2.5. For specific dietary scenario information, see Appendix A, Table A-2-3.

Dietary scenario 2 assigned different dietary surrogates for the carnivore feeding guild. Specifically, benthic invertebrate carnivores (such as the polychaetes *Glycinde armigera* and *Eteone californica*) were assigned the dietary surrogates of sediment and zooplankton (50% for each) compared to 100% sediment in dietary scenario 1.

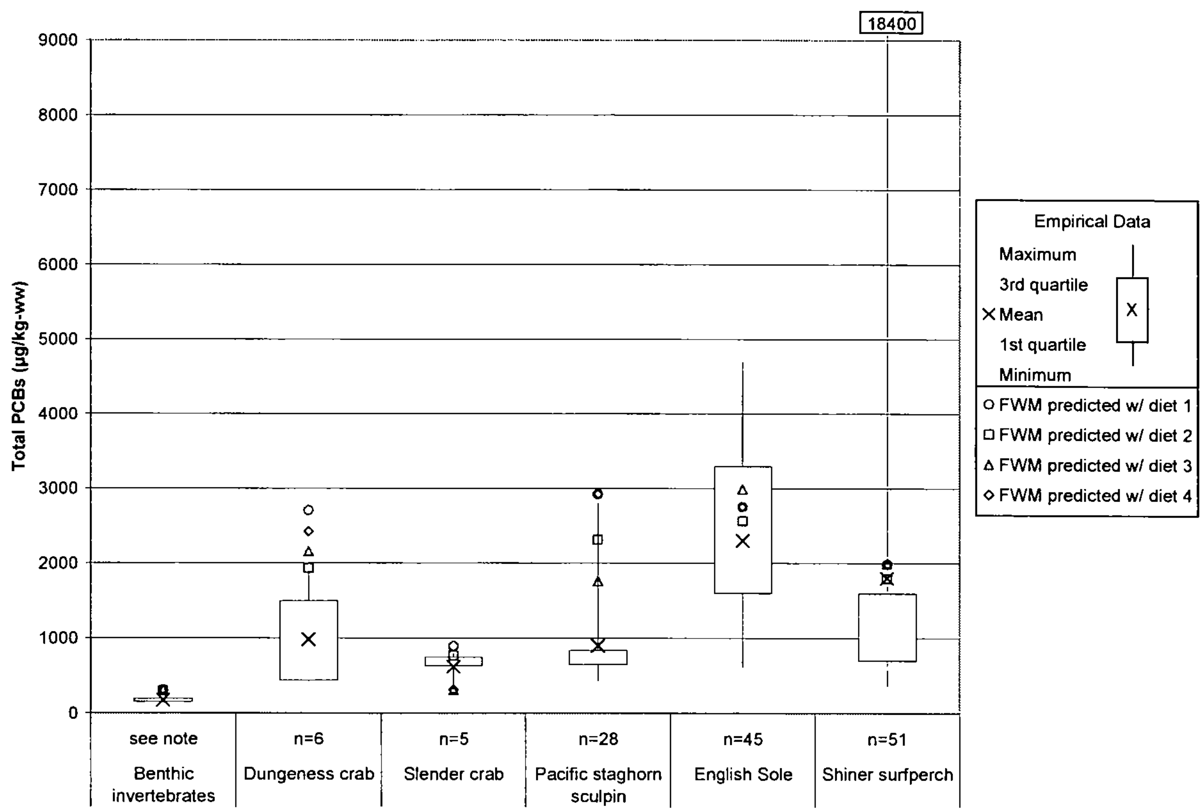
Zooplankton were used as a surrogate prey that could be exposed to PCBs primarily through the water column

See Appendix A for details on the creation of fish and crab diets (Section A.3.1) and benthic invertebrate diets (Section A.2.5).

4.2 RESULTS

Of the four dietary scenarios, dietary scenario 2 resulted in the lowest SPAFs for all species, except Pacific staghorn sculpin, for which dietary scenario 3 performed best (Figure 4-2, Tables 4-1 and 4-2). Dietary scenario 2 used zooplankton as a surrogate for shrimp and juvenile crab, which is a better approximation than using benthic invertebrates as a surrogate (as was done for all other dietary scenarios with the exception of dietary scenario 3 for Pacific staghorn sculpin). The diet in dietary scenario 3 assumed lower fish consumption than the other scenarios, classified shrimp as zooplankton, and assumed sculpin ingest some sediment incidentally.

Figure 4-2. Preliminary model run results for the LDW-wide scale, assuming various dietary scenarios, compared to empirical total PCB concentrations (all datasets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for total PCBs.

Table 4-2. Preliminary LDW-wide model results compared to empirical total PCB concentrations (all datasets combined) for four dietary scenarios

Species[a]	Mean Empirical Total PCBs in Tissue (µg/kg ww)	Model-Predicted Total PCBs in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Dietary Scenario 1					
Benthic invertebrates	170	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800[c]	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	
Dietary Scenario 2					
Benthic invertebrates	170	296	**74%**	**1.7**	+
Juvenile fish	nd	1,164	na	na	na
Slender crab	620	767	**24%**	**1.2**	+
Dungeness crab	980	1,930	**97%**	**2.0**	+
Pacific staghorn sculpin	900	2,314	157%	2.6	+
Shiner surfperch	1,800	1,794	**-0.3%**	**1.0**	-
English sole	2,300	2,565	**12%**	**1.1**	+
All Species					
Mean			**61%**	**1.6**	
Maximum			**157%**	**2.6**	
Minimum			**-0.3%**	**1.0**	
Dietary Scenario 3					
Benthic invertebrates[d]	170	311	83%	1.8	+
Juvenile fish	nd	1,303	na	na	na
Slender crab	620	880	42%	1.4	+
Dungeness crab	980	2,157	120%	2.2	+
Pacific staghorn sculpin	900	1,757	**95%**	**2**	+
Shiner surfperch	1,800	1,998	11%	1.1	+
English sole	2,300	2,990	30%	1.3	+

SPECIES[a]	MEAN EMPIRICAL TOTAL PCBs IN TISSUE (µg/kg ww)	MODEL-PREDICTED TOTAL PCBs IN TISSUE (µg/kg ww)	% DIFFERENCE[b]	SPECIES PREDICTIVE ACCURACY FACTOR[c]	OVERPREDICTION (+) OR UNDERPREDICTION (-)
All Species					
Mean			64%	1.6	
Maximum			120%	2.2	
Minimum			11%	1.1	
Dietary Scenario 4[e]					
Dungeness crab	980	2,421	147%	2.5	+

[a] Phytoplankton have no diet and zooplankton only have one dietary scenario, thus they are not included in this table.

[b] Percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

[c] The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

[d] Benthic invertebrates were run with dietary assumptions from scenario 1 in scenario 3.

[e] Only Dungeness crab has a fourth dietary scenario.

Bold values indicate the best-performing scenarios.

na – not applicable

nd – no data

ww – wet weight

5.0 Sensitivity Analyses

The analysis of model sensitivity involves the investigation of how changes in input parameters affect model output and identifies parameters that most influence model predictions. This analysis provides the basis for determining calibration parameters and for selecting parameters to be evaluated in the uncertainty analysis. Future calibration efforts will focus on the parameters to which the model is most sensitive to determine if values for these parameters should be reassessed and altered, if appropriate, to improve model performance.

Following methods outlined in FWM Memorandum 2 (Windward 2005b), model sensitivity was investigated using two analyses (see Appendix B, Table B-1-1):

- reducing the values of 29 input parameter values by 10%
- altering the value of each of 21 parameters according to its plausible range (using upper- and lower-bound estimates of the mean)

In order to investigate how sensitive the FWM is to total PCBs concentrations in the water column (C_{WT}), a series of water scenarios were run (Section 5.2). Sensitivity of the FWM to C_{WT} is being addressed in more detail than other input parameters to provide additional information to decide whether additional water data should be collected in summer 2006 to support the FWM.

5.1 10% Reduction and Upper- and Lower-Bound Sensitivity Analyses

5.1.1 Methods

In the first analysis (reduction of input parameter values by 10%), all parameter values were changed equally, regardless of the parameter's inherent variability or uncertainty about parameter values. This analysis identified the parameters to which the model output is most sensitive as a result of the mathematical formulation of the FWM. The second analysis (altering input parameter values to the upper and lower bound estimates of the mean) evaluated how known or estimated plausible ranges for parameter values influenced model predictions. This second analysis helped identify the parameters to which the model output is most sensitive as a result of potential variability in the parameter values associated with uncertainty or natural variability in combination with the FWM's mathematical formulation. The plausible range was either generated from empirical data or estimated from literature (see Appendix B). Thus, the plausible range, particularly in the case of site-specific data, such as lipid content, reflects the variability of collected empirical data, but does not account for the full range of true variability or for uncertainty (due to measurement error, etc.)

For both sensitivity analyses, results were evaluated using the species percent difference (SPD). The SPD is a measure of the difference between the prediction for a given species using the initial set of parameter values and the prediction with a specific parameter value altered. The SPD metric is defined as follows:

$$SPD = \frac{NPTC - IPTC}{IPTC} \times 100 \qquad \textbf{Equation 5-1}$$

where:

SPD = species percent difference
NPTC = new predicted tissue concentration
IPTC = initial predicted tissue concentration

Changes in parameter values that increase the predicted tissue concentration will yield a positive SPD and those that decrease the predicted tissue concentration will yield a negative SPD.

In both types of sensitivity analyses, the FWM was run many times, changing one parameter value at a time. The 10% reduction analysis was conducted for most input parameters (29 parameters, see Appendix B, Table B-1-1), and the plausible range analysis was conducted for input parameters for which site-specific or literature empirical range information was available (21 parameters, see Appendix B, Table B-1-1). The complete list of parameters tested and the values and process for selection of values used in each analysis are presented in Appendix B.

For the 10% sensitivity analysis, results were ranked by maximum SPD, and any parameter with a maximum SPD of 8% or more for any species was selected for inclusion in the uncertainty analysis. The threshold of an 8% change in predicted tissue concentration (for any one species) with a 10% change in parameter value was selected, based on best professional judgment, to ensure that parameters to which the model is moderately sensitive are included. A greater than 1:1 response between parameter value change and model prediction change is considered highly sensitive (Arnot 2006).

Also identified were parameters that, when run at the upper or lower end of their plausible range, results in a percentage change that is substantial relative to the change caused by other parameters or relative to the magnitude of change in the input value. These parameters should be considered for evaluation in the uncertainty analysis. In order to select parameters for the uncertainty analysis, results of the plausible range sensitivity analysis were ranked by maximum SPD and the distribution of results was evaluated to see if any patterns or break points arose from the results. Parameters were also ranked according to a relative response ratio (SPD divided by percent change in parameter value). This metric can be compared to the 10% sensitivity analysis to see if percent changes in model predictions were the same for small or large changes in parameter values. All tables in Section 5.1.2 rank results for target species only. Maximum responses for all species are ranked in Appendix B (Table B-3-2).

5.1.2 Results

This section presents a summary of the results of the two sensitivity analyses performed. Full results are presented in Appendix B.

5.1.2.1 Selection of parameters for inclusion in the uncertainty analysis

The results of the 10% reduction sensitivity analysis are presented in Table 5-1. Any parameter identified in the 10% sensitivity analysis as having a maximum species percent difference (SPD) equal to or greater than 8% was included in the uncertainty analysis (see Section 6.0). Thus, the top nine parameters in Table 5-1 were screened into the uncertainty analysis.[7] An exception to the 8% rule was made for K_{OW}. It was selected for inclusion in the uncertainty analysis because it was close to the 8% threshold (7% SPD for Pacific staghorn sculpin), and because it is a key chemical-specific parameter with substantial uncertainty. An additional exception is that the food ingestion rate (G_D), with a maximum SPD of 14%, was not included in the uncertainty analysis. G_D is calculated by an equation within the FWM, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0), cannot test parameters defined by equations.

Table 5-1. Species percent differences for fish and crab species based on a 10% reduction to FWM input parameters

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Dietary absorption efficiency of lipids (alpha)	-24%	PSS	-10%	-14%
Water content	18%	SC	2%	5%
Lipid density	17%	PSS	10%	13%
Food ingestion rate (G_D)	-14%	PSS	-10%	-12%
Lipid content	-14%	PSS	-9%	-11%
Dissolved oxygen (DO)	-11%	PSS	-7%	-9%
Water column temperature	-10%	PSS	-6%	-8%
Dietary absorption efficiency of NLOM (beta)	-9%	DC	-6%	-7%
Sediment PCB concentration	-8%	SC	-8%	-8%
K_{OW} (octanol water partition coefficient)	-7%	PSS	-4%	-5%
Growth rate constant (k_G)	4%	ES	2%	3%
Sediment organic carbon (OC_{sed})	4%	ES	4%	4%
β (MAF, proportionality constant for sorption capacity of NLOM)	-4%	SC	-1%	-2%

[7] When the responses of phytoplankton, zooplankton, and benthic invertebrates are included in the ranking (Appendix B, Table B-3-1), PCB water concentration was also above the 8% threshold.

Parameter	**Maximum SPD**	**Species with Maximum Change**	**Minimum SPD**	**Mean SPD**
PCB concentration in porewater	-3%	ES	-2%	-3%
Organism weight	-3%	PSS	-2%	-2%
Porewater, fraction ventilated	-2%	ES	-2%	-2%
Water PCB concentration	-2%	SS	-2%	-2%
β_{OC} (proportionality constant for sorption capacity of NLOC)	1.8%	ES	1.2%	1.3%
DOC concentration in water column	0.7%	SS	0.6%	0.6%
D_{DOC} (disequilibrium factor for DOC partitioning)	0.7%	SS	0.6%	0.6%
α_{DOC} (proportionality constant for DOC)	0.7%	SS	0.6%	0.6%
k_M (rate constant for PCB metabolic transformation)	0.5%	ES	0.2%	0.3%
POC concentration in water column	0.41%	SS	0.32%	0.37%
D_{POC} (disequilibrium factor for POC partitioning)	0.41%	SS	0.32%	0.37%
α_{POC} (proportionality constant for POC)	0.41%	SS	0.32%	0.37%
A (phytoplankton/algae uptake constant)	0.07%	ES	0.04%	0.05%
B (phytoplankton/algae uptake constant)	0.002%	ES	0.001%	0.001%
Dietary absorption efficiency of water (chi)	-0.0003%	DC/SC	-0.0002%	-0.0003%
Water density	-0.000041%	PSS	-0.00001%	-0.00001%

DC – Dungeness crab

ES – English sole

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Results for the plausible range sensitivity analysis using upper- and lower-bound parameter estimates are presented in Tables 5-2 and 5-3. Table 5-2 presents the variability in model output as a function of variability in each input parameter. Table 5-3 presents the results ranked according to the relative response ratio. By normalizing the magnitude of response to the magnitude of change in input values, this ranking provides insight into the sensitivity of the FWM similar to the 10% change sensitivity analysis. All parameters selected based on the 10% change sensitivity analysis were also identified in the plausible range analysis. In addition, some parameters, beyond those selected in the 10% change analysis, were identified in the plausible range analysis, such as water column temperature and water PCB concentration. The relative response ratio results for the plausible range analysis were consistent with the 10% change sensitivity in that the all parameters with a maximum SPD of 8% or greater for the 10% change sensitivity analysis (Table 5-1, equivalent to a relative response ratio of 0.8 or greater) had a relative response ratio of 0.8 or greater in plausible range analysis (Table 5-3).

Table 5-2. Results of the plausible range sensitivity analysis for predicted fish and crab total PCB concentrations

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Dietary absorption efficiency of lipids (alpha) (upper)	67%	DC	1%	20%
Dietary absorption efficiency of lipids (alpha) (lower)	-54%	DC	-3%	-19%
Dietary absorption efficiency of NLOM (beta) (lower)	-43%	DC	-22%	-29%
Sediment PCB concentration (upper)	42%	SC	40%	41%
Sediment PCB concentration (lower)	-42%	SC	-40%	-41%
Lipid content (upper)	33%	DC	11%	16%
Lipid content (lower)	-31%	DC	-11%	-16%
Dietary absorption efficiency of NLOM (beta) (upper)	28%	DC	12%	18%
Weight (lower)	-25%	DC	-16%	-19%
Lipid density (lower)	20%	PSS	12%	15%
Porewater, fraction ventilated (lower)	-17%	ES	-16%	-17%
Weight (upper)	17%	DC	13%	15%
Lipid density (upper)	-15%	PSS	-9%	-12%
Water column temperature (upper)	12%	PSS	8%	10%
Water column temperature (lower)	-12%	PSS	-8%	-9%
Water PCB concentration (upper)	11%	SS	9%	10%
β (MAF – proportionality constant for sorption capacity of NLOM) (upper)	11%	SC	3%	6%
β (MAF – proportionality constant for sorption capacity of NLOM) (lower)	-11%	SC	-4%	-6%
Dissolved oxygen (DO) (lower)	-10%	PSS	-6%	-8%
Dissolved oxygen (DO) (upper)	10%	PSS	6%	8%
Porewater, fraction ventilated (upper)	8%	ES	6%	6%
α_{DOC} (proportionality constant for DOC) (upper)	-7%	SS	-5%	-6%
K_{OW} (lower)	-6%	PSS	-3%	-5%
K_{OW} (upper)	6%	PSS	3%	4%
α_{DOC} (proportionality constant for DOC) (lower)	6%	SS	4%	5%
Water PCB concentration (lower)	-5%	SS	-4%	-5%
α_{POC} (proportionality constant for POC) (upper)	-5%	SS	-4%	-4%
Water content (lower)	4%	JF	0%	2%
Water content (upper)	-4%	SC	0%	-2%

Parameter	Maximum SPD	Species with Maximum Change	Minimum SPD	Mean SPD
Sediment organic carbon (OC_{sed}) (lower)	3%	ES	3%	3%
α_{POC} (proportionality constant for DOC) (lower)	3%	SS	2%	2%
POC concentration in water column (lower)	2%	SS	2%	2%
Sediment organic carbon (OC_{sed}) (upper)	-1.9%	ES	-1.8%	-1.8%
POC concentration in water column (upper)	-1.5%	SS	-1.2%	-1.4%
DOC concentration in water column (lower)	1.4%	SS	1.0%	1.2%
DOC concentration in water column (upper)	-0.91%	SS	-0.71%	-0.81%
A (phytoplankton/algae uptake constant) (lower)	0.26%	ES	0.15%	0.19%
A (phytoplankton/algae uptake constant) (upper)	-0.22%	ES	-0.13%	-0.16%
B (phytoplankton/algae uptake constant) (lower)	0.010%	ES	0.006%	0.008%
B (phytoplankton/algae uptake constant) (upper)	-0.010%	ES	-0.006%	-0.008%
Water density (upper) (seawater)	0.000007%	PSS	0.000001%	0.000002%

DC – Dungeness crab

ES – English sole

JF – juvenile fish

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Table 5-3. Relative response ratio for upper and lower bound sensitivity analyses for fish and crab species

	Relative Response Ratio		Response to Changes in Input Values			% Change in Parameter Input Values	
Parameter	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
Dietary absorption efficiency of lipids (alpha) (upper)	2.4	0.9	67%	DC	20%	23%	28%
Water content (upper)	-2.2	-1.3	-4%	SC	-2%	2%	2%
Lipid density (lower)	1.8	-1.4	-20%	PSS	15%	-11%	
Lipid density (upper)	-1.4	-1.1	-15%	PSS	-12%	11%	
Dissolved oxygen (DO) (upper)	1.1	0.9	10%	PSS	8%	9%	
Dissolved oxygen (DO) (lower)	1.1	0.9	-10%	PSS	-8%	-9%	
Water column temperature (upper)	1.1	0.9	12%	PSS	10%	11%	

Parameter	Relative Response Ratio: Maximum[a]	Relative Response Ratio: Mean[b]	Response to Changes in Input Values: Maximum SPD	Response to Changes in Input Values: Species with Maximum SPD	Response to Changes in Input Values: Mean SPD	% Change in Parameter Input Values: Mean	% Change in Parameter Input Values: Maximum[c]
Dietary absorption efficiency of NLOM (beta) (upper)	1.0	1.1	28%	DC	18%	17%	28%
Water column temperature (lower)	1.0	0.7	-12%	PSS	-9%	-12%	
Lipid content (upper)	0.9	0.9	33%	DC	16%	18%	39%
Sediment PCB concentration (lower)	0.8	0.8	-42%	SC	-41%	-50%	
Sediment PCB concentration (upper)	0.8	0.8	42%	SC	41%	50%	
Lipid content (lower)	0.8	1.0	-31%	DC	-16%	-16%	-39%
Water content (lower)	0.7	-1.1	-4%	JF	2%	-2%	-6%
K_{OW} (lower)	0.7	0.6	-6%	PSS	-5%	-9%	
Dietary absorption efficiency of lipids (alpha) (lower)	0.7	0.4	-54%	DC	-19%	-52%	-80%
K_{OW} (upper)	0.6	0.4	6%	PSS	4%	10%	
Dietary absorption efficiency of NLOM (beta) (lower)	0.5	0.8	-43%	DC	-29%	-36%	-80%
β (MAF - proportionality constant for sorption capacity of NLOM) (lower)	0.4	0.2	-11%	SC	-6%	-29%	
β (MAF - proportionality constant for sorption capacity of NLOM) (upper)	0.4	0.2	11%	SC	6%	29%	
OC_{sed} (lower)	-0.4	-0.4	3%	ES	3%	-8%	
Porewater, fraction ventilated (lower)	0.3	0.3	-17%	ES	-17%	-55%	-50%
OC_{sed} (upper)	-0.3	-0.3	-1.9%	ES	-1.80%	6%	
Weight (lower)	0.3	0.7	-25%	DC	-19%	-29%	-77%
Weight (upper)	0.3	0.3	17%	DC	15%	57%	55%
Water PCB concentration (lower)	0.2	0.2	-5%	SS	-5%	-25%	
Water PCB concentration (upper)	0.2	0.18	11%	SS	10%	55%	
α_{DOC} (proportionality constant for DOC) (lower)	0.1	-0.08	-6%	SS	5%	-63%	
Porewater, fraction ventilated (upper)	0.08	0.08	8%	ES	6%	75%	100%
DOC (lower)	0.08	-0.07	-1.4%	SS	1.20%	-18%	
DOC (upper)	0.07	-0.06	0.91%	SS	-0.81%	14%	
α_{POC} (proportionality	-0.05	-0.03	3%	SS	2%	-60%	

Parameter	Relative Response Ratio: Maximum[a]	Relative Response Ratio: Mean[b]	Response to Changes in Input Values: Maximum SPD	Response to Changes in Input Values: Species with Maximum SPD	Response to Changes in Input Values: Mean SPD	% Change in Parameter Input Values: Mean	% Change in Parameter Input Values: Maximum[c]
constant for POC) (lower)							
α_{DOC} (proportionality constant for DOC) (upper)	-0.05	-0.04	-7%	SS	-6%	150%	
POC (lower)	-0.04	-0.04	2%	SS	2%	-45%	
POC (upper)	-0.04	-0.03	-1.50%	SS	-1.40%	41%	
α_{POC} (proportionality constant for POC) (upper)	-0.03	-0.03	-5%	SS	-4%	149%	
A (phytoplankton/ algae uptake constant) (lower)	0.01	0.01	0.26%	ES	0.19%	33%	
A (phytoplankton/ algae uptake constant) (upper)	0.01	0.00	-0.22%	ES	-0.16%	-33%	
B (phytoplankton/ algae uptake constant) (upper)	0.0001	-0.0001	0.01%	ES	-0.01%	67%	
B (phytoplankton/ algae uptake constant) (lower)	0.0001	0.0001	-0.01%	ES	-0.01%	-67%	
Water density (upper) (seawater)	0.000004	0.000001	0.000007%	PSS	0.000002%	2%	

[a] Maximum percent change used for species-specific parameters only.

[b] Calculated as the mean species percent difference divided by the mean percent change in parameter value.

[c] Percent change for species-specific parameters only.

DC – Dungeness crab

ES – English sole

JF – juvenile fish

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

SPD – species percent difference

DOC – dissolved organic carbon

POC – particulate organic carbon

Of the 21 parameters evaluated in the upper- and lower-bound analyses, 11 had maximum responses for fish and crab species greater than 8% (Table 5-2). Five of the parameters had maximum responses greater than 20%. Six of the parameters had maximum responses between 10 and 20%. Three of the parameters had maximum responses between 5 and 10%, and seven of the parameters had maximum responses between 0 and 5%. A 10% change in predicted tissue concentrations is considered to be an important change if only one parameter is altered, and thus 10% was selected as the threshold for the upper- and lower-bound analysis.

With the threshold for further analysis at 10%, 11 parameters were selected for inclusion in the uncertainty analysis. When maximum SPDs resulting from the plausible range analysis were ranked for all species (Table B-3-2), three additional parameters had maximum SPDs of 10% or greater (Appendix B). Two of these parameters (α_{DOC} and α_{POC}) are environmental parameters related to the bioavailability of PCBs in water. They were not included in the uncertainty analysis because they are constants in equations in the FWM rather than true input parameters, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0) cannot test parameters within equations. The phytoplankton/algae uptake constant (A) was included in the uncertainty analysis as a result of advice from Jon Arnot based on his previous experience with other model applications (Arnot 2005). Table 5-4 presents all the parameters selected for the uncertainty analysis and the rationale for their inclusion.

Table 5-4. Parameters selected for the uncertainty analysis

Parameters Selected for the Uncertainty Analyses	Rationale for Inclusion
A (phytoplankton/algae uptake constant)	Advice from Jon Arnot (2005) and plausible range results (Table B-3-2)
β (MAF, proportionality constant for sorption capacity of NLOM)	Plausible range results (Tables 5-2 and B-3-2)
Dietary absorption efficiency of lipids (alpha)	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Dietary absorption efficiency of NLOM (beta)	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Dissolved oxygen	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
K_{ow}	10% results (Table B-3-1) and because K_{OW} is included in numerous equations in the model
Lipid content	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Lipid density	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
POC	Plausible range results (Tables 5-2 and B-3-2)
Porewater, fraction ventilated	Selected because parameter is highly uncertain (middle of ranking for plausible range, all species)
Sediment PCB concentration	10% and plausible range results (Tables 5-1, 5-2, B-3-1, and B-3-2)
Temperature water column	10% and plausible range results (Tables 5-1. B-3-1, and B-3-2),
Water content	10% and plausible range results (Tables 5-1. B-3-1, and B-3-2),
Water PCB concentration	Plausible range results (Tables 5-2 and B-3-2); 10% results (Table B-3-1)
Weight	Plausible range results (Tables 5-2 and B-3-2)

5.1.2.2 Evaluation of model sensitivity to parameters

Table 5-4 presents parameters selected for the uncertainty analyses, but also serves as a list of sensitive parameters for the FWM. This list of parameters will serve as a guide for future calibration. Parameters to which the FWM is most sensitive and have the highest potential variability or uncertainty will have the greatest impact on predicted

PCB tissue concentrations during calibration. Those parameters with a combination of high sensitivity and high uncertainty (e.g., dietary absorption efficiency of lipids) will be calibrated to ensure that a selected parameter value is falling within a true range of plausible mean values. Parameters to which phytoplankton are sensitive, but fish and crab are not (i.e., phytoplankton A and α_{DOC} and α_{POC}), will not be useful parameters for calibrating the FWM for target species. Phytoplankton will not be calibrated because no empirical PCB tissue data exist for this model compartment.

5.2 Water Scenarios

This section presents the results of preliminary model runs to assess the sensitivity of the FWM to total PCB concentrations in the water column. Water sensitivity is being addressed in more detail than other input parameters to provide additional information to decide whether additional water data should be collected in 2006 to support the FWM. The need for collection of additional surface water data will be determined in late spring 2006 based on: 1) the sensitivity of the FWM to total PCB concentrations in water, 2) the relative uncertainty in model predictions attributable to the uncertainty in total PCB concentrations in water versus other parameters, and 3) the variability of total PCB concentrations in water over smaller spatial scales, as predicted by the EFDC model and magnitude of effect on FWM predictions.

5.2.1 Methods

The FWM with the initial set of input values was run at the LDW-wide spatial scale five times with five different total PCB concentrations in water (1, 2, 3, 5, and 10 ng/L). These concentrations were selected to evaluate model sensitivity at empirical concentrations detected in the LDW in August 2005 (1 to 3 ng/L) and to evaluate model sensitivity at higher concentrations (up to 10 ng/L). The PCB concentrations in water to be used in the model runs for the Phase 2 RI will ultimately be determined based on output from the recalibrated EFDC model (as discussed in Sections 8.0 and 9.0).

5.2.2 Results

To assess the sensitivity of the FWM to changes in total PCB concentrations in water, total PCB concentrations in tissue were predicted using each of the five different total PCB concentrations in water. These predictions were then compared to empirical data to assess both FWM performance (as measured by SPAFs; Table 5-5) and the sensitivity of the WM to variation in total PCB water concentrations (i.e., differences in predictions of total PCB tissue concentrations relative to differences in total PCB water concentrations; Table 5-6).

Model performance (as measured by SPAFs) was best for the lowest water concentration (1 ng/L) (Table 5-5; Figure 5-1). This result is consistent with the fact that the FWM is generally over-predicting (Section 3.2) based on the initial set of parameters (which assumed a water concentration of 2 ng/L). At the highest water concentration (10 ng/L), the average SPAF was 3.3 (with species-specific SPAFs ranging from 2.0 to 5.7) compared to an average SPAF of 1.8 (with species-specific SPAFs ranging from 1.9 to 2.9) for the 1 ng/L scenario.

Table 5-5. Preliminary LDW-wide FWM results for five water scenarios compared to empirical total PCB tissue concentrations (all data sets combined)

Species	Mean Empirical Total PCBs Tissue Concentration[a] (µg/kg ww)	Model-Predicted Total PCBs Tissue Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Water Scenario with 1 ng/L Total PCBs in Water					
Various phytoplankton	nd	24	na	na	na
Various zooplankton	nd	36	na	na	na
Benthic invertebrates	170[d]	290	71%	1.7	+
Juvenile fish	nd	1,186	na	na	na
Slender crab	620	822	33%	1.3	+
Dungeness crab	980	2,453	150%	2.5	+
Pacific staghorn sculpin	900	2,641	193%	2.9	+
Shiner surfperch	1,800	1,781	-1%	1.0	-
English sole	2,300	2,527	10%	1.1	+
All Species					
Mean			76%	1.8	
Maximum			193%	2.9	
Minimum			-1%	1.0	
Water Scenario with 2 ng/L Total PCBs in Water					
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	170[d]	311	83%	1.8	+
Juvenile fish	nd	1,315	na	na	na
Slender crab	620	893	44%	1.4	+
Dungeness crab	980	2,705	176%	2.8	+
Pacific staghorn sculpin	900	2,921	225%	3.2	+
Shiner surfperch	1,800	1,986	10%	1.1	+
English sole	2,300	2,752	20%	1.2	+
All Species					
Mean			93%	1.9	
Maximum			225%	3.2	
Minimum			10%	1.1	
Water Scenario with 3 ng/L Total PCBs in Water					
Various phytoplankton	nd	71	na	na	na
Various zooplankton	nd	109	na	na	na
Benthic invertebrates	170[d]	332	95%	2.0	+
Juvenile fish	nd	1,444	na	na	na
Slender crab	620	964	55%	1.6	+

Species	Mean Empirical Total PCBs Tissue Concentration[a] (µg/kg ww)	Model-Predicted Total PCBs Tissue Concentration (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Dungeness crab	980	2,958	202%	3.0	+
Pacific staghorn sculpin	900	3,202	256%	3.6	+
Shiner surfperch	1,800	2,190	22%	1.2	+
English sole	2,300	2,976	29%	1.3	+
All Species					
Mean			110%	2.1	
Maximum			256%	3.6	
Minimum			22%	1.2	
Water Scenario 5 ng/L Total PCBs in Water					
Various phytoplankton	nd	118	na	na	na
Various zooplankton	nd	181	na	na	na
Benthic invertebrates	170[b]	373	119%	2.2	+
Juvenile fish	nd	1,702	na	na	na
Slender crab	620	1,106	78%	1.8	+
Dungeness crab	980	3,463	253%	3.5	+
Pacific staghorn sculpin	900	3,762	318%	4.2	+
Shiner surfperch	1,800	2,598	44%	1.4	+
English sole	2,300	3,426	49%	1.5	+
All Species					
Mean			144%	2.4	
Maximum			318%	4.2	
Minimum			44%	1.4	
Water Scenario 10 ng/L Total PCBs in Water					
Various phytoplankton	nd	236	na	na	na
Various zooplankton	nd	363	na	na	na
Benthic invertebrates	170[b]	477	181%	2.8	+
Juvenile fish	nd	2,347	na	na	na
Slender crab	620	1,461	136%	2.4	+
Dungeness crab	980	4,725	383%	4.8	+
Pacific staghorn sculpin	900	5,162	474%	5.7	+
Shiner surfperch	1,800	3,618	101%	2.0	+
English sole	2,300	4,549	98%	2.0	+
All Species					
Mean			228%	3.3	
Maximum			474%	5.7	
Minimum			98%	2.0	

a Empirical data from historical and Phase 2 (2004 and 2005) combined.

b The percent difference is the difference between the predicted and empirical tissue chemical concentration divided by the empirical tissue chemical concentration.

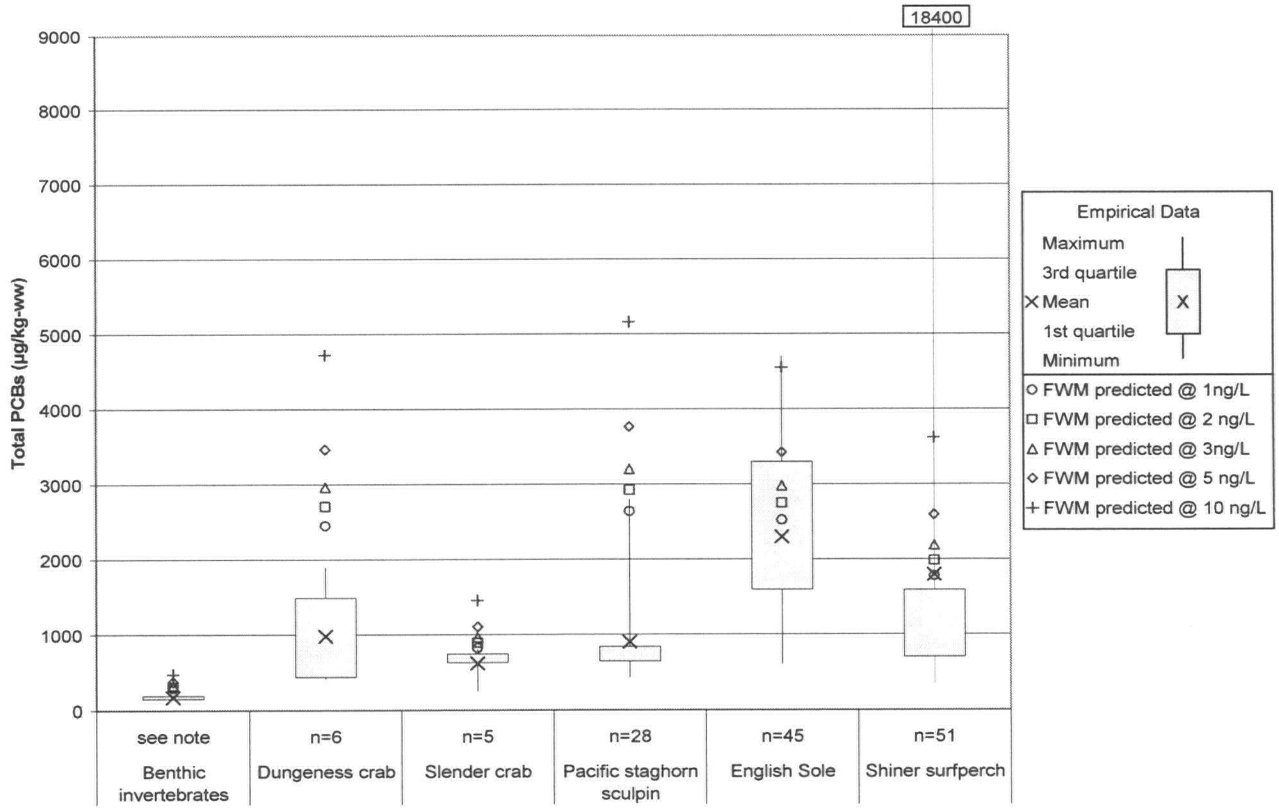
c The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

d Concentration predicted from sediment-tissue PCB regression at an LDW-wide PCB SWAC of 250 µg/kg dw.

na – not applicable – no data

ww – wet weight

Figure 5-1. Preliminary model run results for the LDW-wide scale for five water scenarios compared to empirical total PCB tissue concentrations (all data sets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the LDW-wide SWAC for PCBs.

Table 5-6 presents predicted total PCB concentrations in tissue for the five water concentrations and reports the factor by which predictions at each water concentration differ from tissue predictions at 1 ng/L. These results indicate that predicted total PCB tissue concentrations in species with high water dependencies (e.g., phytoplankton) are highly sensitive to total PCB water concentrations (i.e., a 10-fold change in the total PCB water concentration resulted in a 10-fold change in the predicted total PCB concentration in phytoplankton). The FWM was less sensitive to water concentrations when predicting total PCB concentrations for crab and fish tissues (i.e., a 10-fold change in the water concentration resulted in a two-fold change in the predicted total PCB concentration in crabs or fish).

Table 5-6. Model sensitivity to total PCB concentration in water based on preliminary LDW-wide model runs for five water scenarios

Species	Water Scenarios								
	1 ng/L PCB Concentration in Water	2 ng/L PCB Concentration in Water		3 ng/L PCB Concentration in Water		5 ng/L PCB Concentration in Water		10 ng/L PCB Concentration in Water	
	Model Predicted Total PCBs in Tissue (µg/kg ww)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 2 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 3 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 5 and 1 ng/L)	Model Predicted Total PCBs in Tissue (µg/kg ww)	Factor Difference (between 10 and 1 ng/L)
Various phytoplankton	24	47	2.0	71	3.0	118	5.0	236	10
Various zooplankton	36	73	2.0	109	3.0	181	5.0	363	10
Benthic invertebrates	290	311	1.1	332	1.1	373	1.3	477	1.6
Juvenile fish	1,186	1,315	1.1	1,444	1.2	1,702	1.4	2,347	2.0
Slender crab	822	893	1.1	964	1.2	1,106	1.3	1,461	1.8
Dungeness crab	2,453	2,705	1.1	2,958	1.2	3,463	1.4	4,725	1.9
Pacific staghorn sculpin	2,641	2,921	1.1	3,202	1.2	3,762	1.4	5,162	2.0
Shiner surfperch	1,781	1,986	1.1	2,190	1.2	2,598	1.5	3,618	2.0
English sole	2,527	2,752	1.1	2,976	1.2	3,426	1.4	4,549	1.8
All Species									
Average factor difference			1.3		1.6		2.2		3.7
Maximum factor difference			2.0		3.0		5.0		10
Minimum factor difference			1.1		1.1		1.3		1.6

ww – wet weight

6.0 Uncertainty Analysis

An uncertainty analysis evaluates the effect of uncertainty in input parameters on model output. The purpose of this uncertainty analysis was to characterize quantitatively the combined effect of selected parameters' uncertainties on the prediction of total PCB concentrations in tissue. Parameters were selected based on the results of the sensitivity analyses (see Section 5.0). As discussed in FWM Memorandum 2 (Windward 2005b), the uncertainty analysis was performed by Monte Carlo simulation using Decisioneering® Crystal Ball® Version 7.0 software for the LDW-wide scale. The results of the uncertainty analysis can be used to evaluate confidence in model output (e.g., what is the distribution of model estimates when the uncertainty in input parameters is considered?).

6.1 METHODS

In Monte Carlo simulation modeling, probability distributions, rather than point estimates, are assigned for input parameters if sufficient data are available to describe the distribution and if the FWM is sensitive to a given parameter. The probability distributions reflect the relative likelihood of different values for each parameter. For the purpose of this analysis, parameter uncertainty includes both uncertainty (because of insufficient information) and variability (because of inherent differences in parameter values).

Using Crystal Ball® software, the Monte Carlo version of the FWM was run 10,000 times. During each model iteration, different combinations of values for each input parameter were randomly selected from the probability distribution for each parameter. In contrast to the sensitivity analysis where only one parameter was varied at a time, all parameters in the Monte Carlo uncertainty analysis are varied simultaneously during each model iteration. Output from this uncertainty analysis consists of distributions of the relative probability of predicted tissue concentrations for each species based on the distributions of FWM input parameter values. This information is useful for calibrating the FWM and interpreting model results.

6.1.1 Assigning distributions for model parameters

The first step in running the Monte Carlo model is the development of parameter distributions. Parameters were included in the uncertainty analysis if they were identified as sensitive in the sensitivity analysis (Section 5.0). Because these parameters have the greatest effect on model output, they were further investigated in the uncertainty analysis.

The same datasets used to develop the initial set of values for the FWM and the sensitivity analyses were used to identify distributions for parameters included in the uncertainty analysis. In assigning these distributions, relevant data for each parameter were considered. As recommended by MacIntosh et al. (1994), the assignment of a distribution was influenced by the quality of the available data. The approaches for developing distributions to represent variability and uncertainty of each parameter, as well as actual distribution assignment for each parameter, are described in detail in Appendix C. Distributions were developed for 10 non-species-specific environmental, chemical, and biological parameters, and 45 species-specific parameters (e.g., nine lipid content parameters, one for each of the nine modeled species). The distributions were selected such that the initial set of model values for the LDW-wide scale (as described in Section 3.1 and Appendix A) were always the mean or mode of the distribution assigned for the parameters included in the uncertainty analysis (Appendix C). These distributions were entered into the Monte Carlo version of the FWM.

6.1.2 Correlation

Some parameters, such as percent lipids and water content, are expected to be correlated in organisms. The assignment of correlation coefficients for correlated parameters prevents improbable combinations of values. For example, if water content and lipid content are inversely correlated, a combination of high lipid content and high water content values will not be allowed. Thus, inclusion of correlations in the FWM for these parameters reduces the likelihood of unrealistic combinations of different parameters during model iterations. To evaluate correlations, data that can be reasonably matched (in time and location or by sample specimens) must be available and be similarly robust in terms of number of samples and data quality. For parameter pairs expected to be correlated for biological or environmental reasons, a correlation test was performed if adequate data for the test were available. Correlation coefficients were calculated for several water quality parameters (i.e., water temperature, dissolved oxygen, and particulate organic carbon) and biological parameters (i.e., species lipid content and water content) and included in the Monte Carlo version of the model. The assignment of parameter correlations is discussed in detail in Appendix C.

6.2 Results

The results of the Monte Carlo modeling are distributions of predicted total PCB tissue concentrations for the five target species. These distributions describe the uncertainty of the FWM in predictions for different species.

An example of the Monte Carlo model output is presented in Figure 6-1. The output in this example is a frequency distribution of model predictions of total PCB concentrations in English sole tissue. Figure 6-2 shows the same English sole predictions as a cumulative frequency distribution. In both figures, the left y-axis indicates the probability of particular output values, and the right y-axis indicates the frequency of output values. Note that the total number of output values is 10,000 (the number of model iterations). The cumulative frequency presentation is commonly used for Monte Carlo model results because it allows the viewer to easily identify different percentiles of prediction likelihood. For example, the 95th percentile probability is approximately 3,800 µg/kg ww for English sole (i.e., 95% of the Monte Carlo model results are below 3,800 µg/kg ww).

Figure 6-1. Frequency distribution results from the Monte Carlo model showing the relative probabilities of predicted total PCB concentrations in English sole tissue

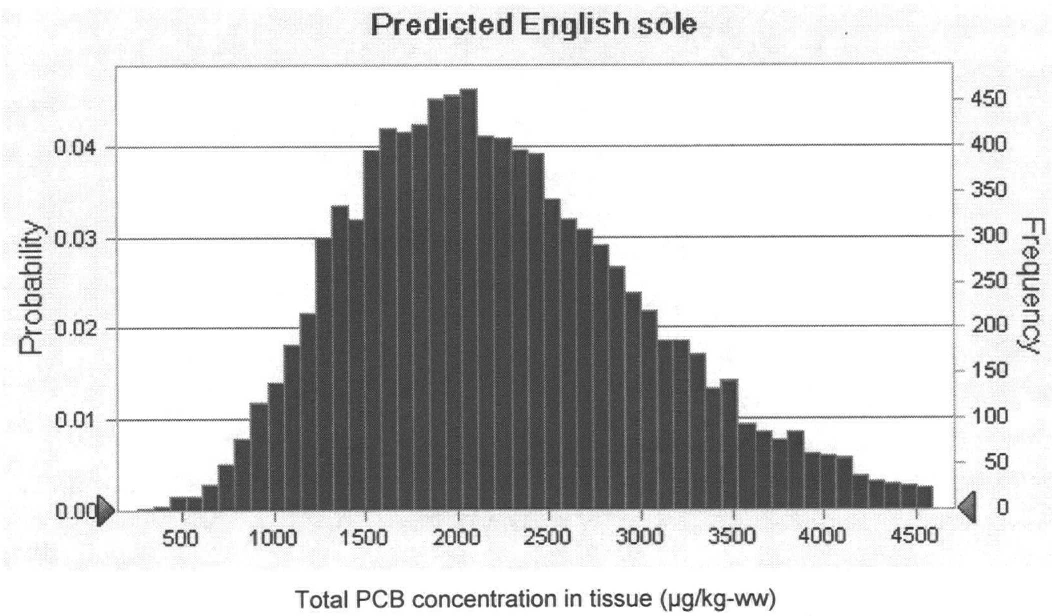
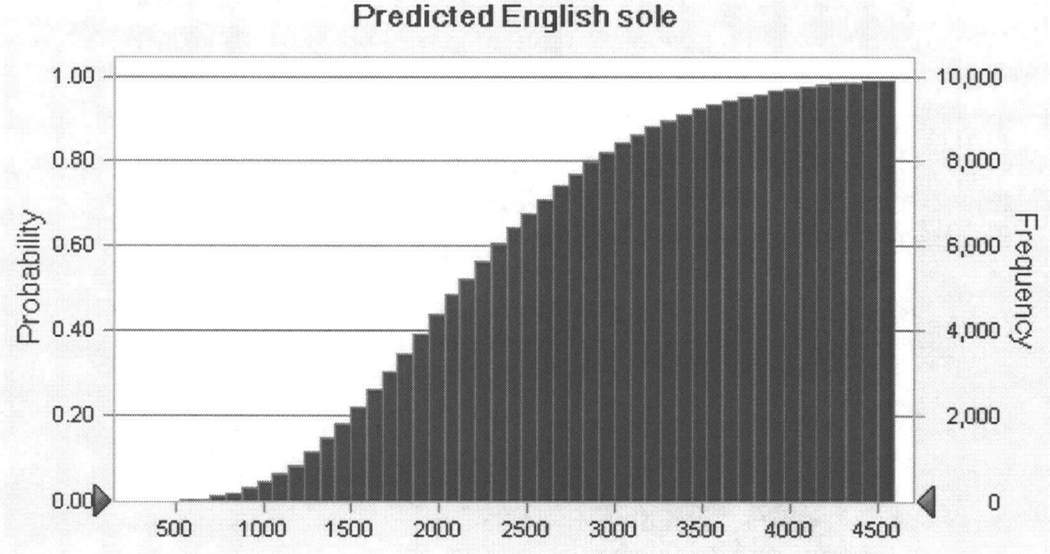


Figure 6-2. Cumulative frequency results from the Monte Carlo model showing predicted total PCB concentrations in English sole tissue



Total PCB concentration in English sole tissue (µg/kg-ww)

Table 6-1 provides a summary of model output and a comparison of predictions to empirical data for all modeled species. The 5th, 50th, and 95th percentiles and mean of the model predictions provide a general description of the model output. The full range of model output includes the extreme minimum and maximum predictions from the FWM, which are also among the least likely model predictions.

Table 6-1. Results of the preliminary uncertainty assessment conducted on an LDW-wide scale

Species	Uncertainty Assessment Results					Empirical Tissue Data			Source of Empirical Data
	5th Percentile Predicted Total PCB Concentration in Tissue (µg/kg ww)	50th Percentile (Median) Predicted Total PCB Concentration in Tissue (µg/kg ww)	95th Percentile Predicted Total PCB Concentration in Tissue (µg/kg ww)	Range of Predicted Total PCB Concentration in Tissue (µg/kg ww)	Mean of Predicted Total PCB Concentration in Tissue (µg/kg ww)	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)	Median Empirical Total PCB Concentration in Tissue (µg/kg ww)	Range of Empirical Total PCB Concentration in Tissue (µg/kg ww)	
Phytoplankton	28	45	66	8 – 93	46	nd	nd	nd	
Zooplankton	36	69	116	7 – 192	71	nd	nd	nd	
Benthic invertebrates	117	253	459	16 – 807	266	170[a]	na	136 – 200[a]	Predicted based on a SWAC of 250 µg/kg dw total PCBs in sediment and a tissue-sediment regression derived from 20 co-located benthic invertebrate and surface sediment samples collected in Phase 2 (2004)
Juvenile fish	488	1,047	1,925	150 – 3,695	1,107	nd	nd	nd	
Slender crab	281	571	1,101	56 – 2,608	614	620[b]	650[b]	250 – 800[b]	Phase 2 (2004, 2005) data
Dungeness crab	465	1,596	3,910	30 – 10,377	1,816	1,000[b]	640[b]	420 – 1,900[b]	Historical and Phase 2 (2004, 2005) data
Pacific staghorn sculpin	1,021	2,277	4,269	325 – 7,972	2,411	900	720	430 – 2,800	Phase 2 (2004, 2005) data
Shiner surfperch	703	1,552	2,863	175 – 4,940	1,637	1,800	1,120	350 – 18,000	Historical and Phase 2 (2004, 2005) data
English sole	1,075	2,152	3,796	259 – 7,294	2,257	2,300	1,885	610 – 4,700	Phase 2 (2004, 2005) data

[a] Concentration predicted from sediment-tissue PCB regression at an LDW-wide total PCB SWAC of 250 µg/kg dw (for mean) or plausible range of 125 to 375 µg/kg dw. See Appendix B (Section B.2.2) for details on range selection.

[b] Based on mean Phase 2 (2004, 2005) data. Whole-body total PCB concentrations in crabs were calculated as weighted means [(0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)].

dw – dry weight
na – Not applicable – insufficient information to calculate median (range based on upper and lower estimated concentrations [see footnote a]).
nd – no data
SWAC – spatially weighted average concentration
ww – wet weight

The predicted means presented in Table 6-1 differ from the predicted concentrations presented in Table 3-2 because the values in the Table 6-1 are the mean of 10,000 estimates generated by the Monte Carlo analysis. Table 3-2 presents the best single estimate using the model. The predicted tissue concentrations in Table 3-2 are higher than the predicted means in Table 6-1. This difference reflects the parameter distributions included in the Monte Carlo model, which overall were skewed to the left (see Appendix C for details on distributions).

Dungeness crab was the species with the widest range of predicted total PCB concentrations. The range is probably widest for Dungeness crab for two reasons. First, invertebrates have wider ranges than fish for some key estimated parameters (such dietary absorption of lipids and NLOM). Second, Dungeness crab is a higher-trophic-level species and thus has more uncertain parameters contributing to the distribution than phytoplankton, for example. In future FWM calibration, efforts will be directed toward refining the model parameters that should create the greatest reductions in the model's uncertainty. Knowing which species have the largest range of output from the Monte Carlo model can be useful for focusing these efforts.

The range of empirical total PCB concentrations for shiner surfperch was much greater than that for other species, and the model predictions did not bound this range (Table 6-1). In particular, there was one shiner surfperch sample with an exceptionally high concentration (18,000 µg/kg). The Monte Carlo model predictions did not bound the highest empirical total PCB concentration for shiner surfperch.

Comparison of several other predicted and empirical summary statistics provides confidence in the distributional shape of the output and predictive capability of the uncertainty model. In all cases, species-specific predicted means exceeded predicted medians (50th percentile). Means were also greater than medians in empirical data on a species-specific basis, indicating that there is some similarity between empirical and predicted distributions. In addition, the 5th and 95th percentiles of predicted tissue concentrations were, with the exception of shiner surfperch, within a factor of 3 or better of the empirical minimum and maximum concentrations, respectively. Taken together, these results indicate that the model, with uncertainty considered, provides predictions that are consistent with the variability of empirical total PCB concentrations in fish and crab tissue.

In summary, the Monte Carlo model results bolster overall confidence in model predictions because the predicted distribution of total PCB tissue concentrations is similar to the distribution of empirical total PCB tissue concentrations. The Monte Carlo model results may be used to focus future modeling efforts on parameters important for species with the largest variations between empirical and predicted tissue concentration distributions, based on both the shape of the distributions and the numerical values. In addition to potentially improving future single-point "best estimate" model predictions (non-Monte Carlo model runs), calibration efforts may also help reduce the uncertainty for some parameters, and therefore, reduce the variability of model output (uncertainty range) in future Monte Carlo model analyses. The modeling presented in this memorandum has been performed on an initial model input parameterization (see Section 2.0). Once the FWM is calibrated, the variability in the Monte Carlo output will be reassessed and summarized in the Phase 2 RI.

7.0 Smaller Spatial Scales

In addition to the LDW-wide scale, the FWM was also run at the smaller spatial scale of the four modeling areas (Figure 2-1). This section presents the results of the modeling-area-scale runs.

Modeling areas were defined as the four fish and crab tissue sampling areas extended out to the center point between tissue sampling areas (Figure 2-1). This scale was selected because it represents a smaller scale than the LDW-wide scale that can still be directly compared to empirical data on a similar scale from the LDW. Most of the modeled species are likely to have foraging areas that are smaller than the entire LDW based on consultation with local fish experts, although uncertainty exists regarding the absolute size of these areas. Therefore, two different spatial scales are being modeled (i.e., LDW-wide and modeling area scales). This section presents the results of the modeling area scale runs.

7.1 Methods

Input parameter values that were changed from those used in the LDW-wide scale in order to run the FWM on the modeling area spatial scale included the total PCB concentration in sediment, the organic carbon content of the sediment, fish and invertebrate lipid contents and water contents, and fish and crab weights. Otherwise, all input parameter values used in the preliminary LDW-wide model runs were used (including dietary scenario 1). Specific parameter values for the modeling areas are presented in the input parameter value tables in Appendix A (Tables A-1-2, A-2-1, A-2-2, A-2-3, A-3-1, and A-4-1). Predicted total PCB concentrations in tissue were compared to empirical data from the area modeled.

7.2 Results

Table 7-1 and Figure 7-1 present initial model results for the four modeling areas. Predicted total PCB concentrations in fish and crab tissue were generally within a factor of 3 and less than 200% different from empirical total PCB concentrations for most species. Predictions for Dungeness crabs and Pacific staghorn sculpin were generally higher than empirical data, but were still within a factor of 5 and less than 400% different from empirical concentrations for all modeling areas. Further refinement of the FWM will be conducted for Dungeness crabs and Pacific staghorn sculpin if this scale is deemed appropriate for these target species.

Table 7-1. Preliminary model run results at the modeling area scale compared to empirical total PCB tissue concentrations (all data sets combined)

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)[a]	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Modeling Area 1					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	180	363	102%	2.0	+
Juvenile fish	nd	1,483	na	na	na
Slender crab	650	947	46%	1.5	+
Dungeness crab	830	3,569	330%	4.3	+
Pacific staghorn sculpin	720	3,392	371%	4.7	+
Shiner surfperch	970	2,100	116%	2.2	+
English sole	2,600	2,970	14%	1.1	+
All Species					
Mean			163%	2.6	
Maximum			371%	4.7	
Minimum			14%	1.1	
Modeling Area 2					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	150	253	69%	1.7	+
Juvenile fish	nd	1,037	na	nc	na
Slender crab	600	661	10%	1.1	+
Dungeness crab	nd	2,048	na	na	na
Pacific staghorn sculpin	750	2,343	212%	3.1	+
Shiner surfperch	2,800	1,592	-43%	1.8	-
English sole	2,900	2,319	-20%	1.3	-
All Species					
Mean			46%	1.8	
Maximum			212%	3.1	
Minimum			-43%	1.1	
Modeling Area 3					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	220	426	94%	1.9	+
Juvenile fish	nd	1,892	na	na	na
Slender crab	630	1,272	102%	2	+
Dungeness crab	1,000	3,131	213%	3.1	+
Pacific staghorn sculpin	1,400	3,919	180%	2.8	+
Shiner surfperch	2,700	2,938	9%	1.1	+
English sole	2,000	3,893	95%	1.9	+
All Species					
Mean			115%	2.1	
Maximum			213%	3.2	

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)[a]	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[b]	Species Predictive Accuracy Factor[c]	Overprediction (+) or Underprediction (-)
Minimum			9%	1.1	
Modeling Area 4					
Phytoplankton	nd	47	na	na	na
Zooplankton	nd	73	na	na	na
Benthic invertebrates	92	76	-17%	1.2	-
Juvenile fish	nd	409	na	na	na
Slender crab	nd	257	na	na	na
Dungeness crab	1,200	774	-36%	1.6	-
Pacific staghorn sculpin	730	842	15%	1.2	+
Shiner surfperch	840	661	-21%	1.3	-
English sole	1,400	781	-44%	1.8	-
All Species					
Mean			-21%	1.4	
Maximum			15%	1.8	
Minimum			-44%	1.2	

[a] Empirical data from historical and Phase 2 (2004 and 2005) combined. Empirical data were not directly used for benthic invertebrates. Instead, the concentrations presented for benthic invertebrates are based on a tissue/sediment regression.

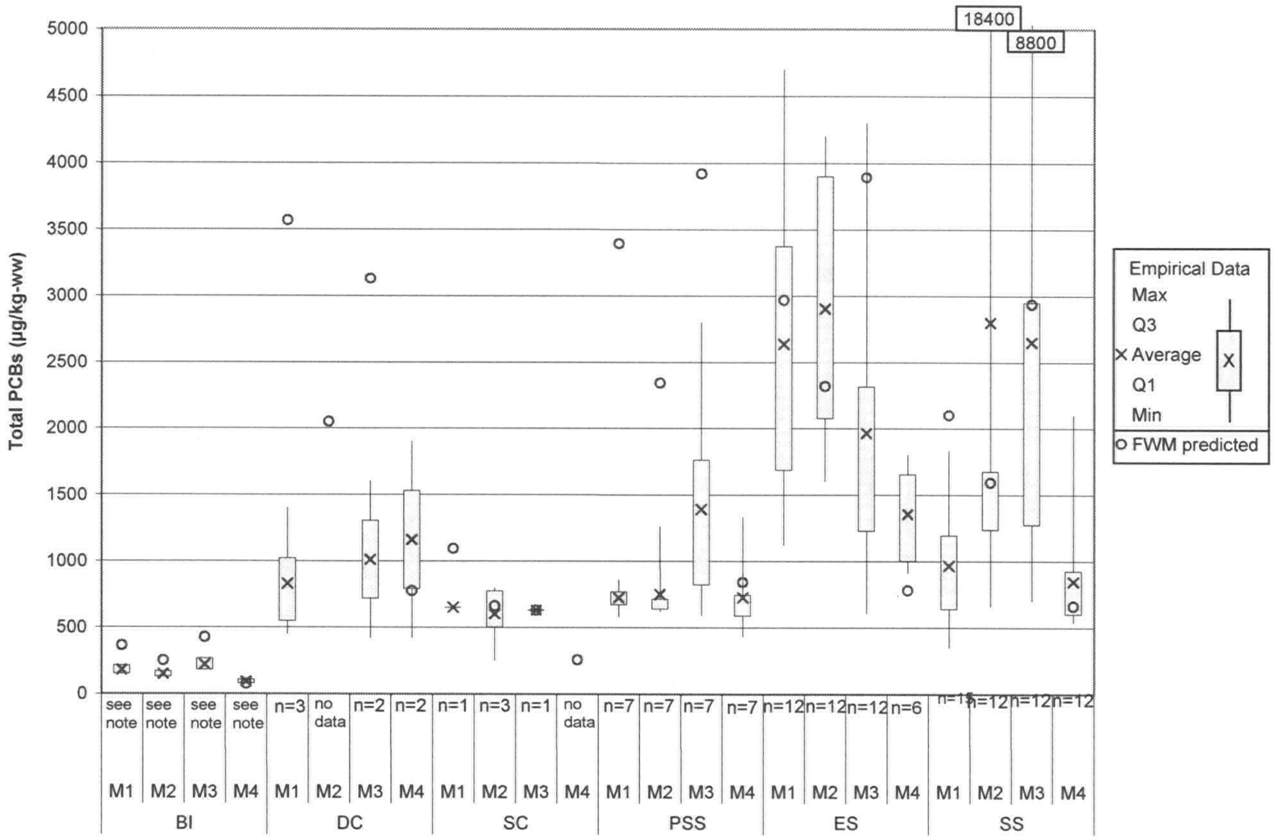
[b] The percent difference is the difference of the predicted and empirical tissue chemical concentration divided by the empirical tissue chemical concentration.

[c] The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

na – not applicable

nd – no data

Figure 7-1. Preliminary model run results at the modeling-area scale compared to empirical total PCB tissue concentrations (all data sets combined)



Note – Empirical benthic invertebrate data distributions represented by the green bar are the mean and 95% upper- and lower-confidence interval concentrations predicted using the benthic invertebrate sediment-tissue regression and the SWACs for total PCBs for each of the four modeling areas.

M1 through M4 – modeling areas 1 through 4

BI – benthic invertebrate

DC – Dungeness crab

ES – English sole

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

Predictions for modeling area 4 were most similar to empirical data, with a mean SPAF of 1.4 and mean percent difference of -21%. For this modeling area, concentrations of total PCBs in all species except Pacific staghorn sculpin were under-predicted. Predictions for modeling area 2 were also similar to empirical data (mean SPAF of 1.8, mean percent difference of 46%). In this area, concentrations for shiner surfperch and English sole were under-predicted, whereas concentrations in benthic invertebrates, slender crabs, and Pacific staghorn sculpin were over-predicted. Modeling area 2 had no empirical data for Dungeness crabs, so the mean SPAF for that modeling area was an average of five instead of six species. Dungeness crabs had higher SPAFs and percent differences than the other modeled species for modeling areas 1 and 3, increasing the mean SPAF and percent difference for those areas.

8.0 Lessons Learned

The purpose of this memorandum is to present preliminary results of the FWM to further elucidate model assumptions and sensitivities. This section presents an overview of key findings as well as key sensitivities and uncertainties to consider in the final phase of the food web modeling to be included in the Phase 2 RI.

8.1 Model Performance

This memorandum presented preliminary model results for five target species (Dungeness crab, slender crab, English sole, shiner surfperch, and Pacific staghorn sculpin). As discussed in Section 1.0, these model results are preliminary pending final resolution of water data, sediment interpolation, and a few other key assumptions in the FWM (e.g., dietary scenarios). In general, however, the predicted concentrations of total PCBs in tissues of the five target species were within a factor of 3.2 of empirical data (all datasets combined) on the LDW-wide scale (Table 3-2), and therefore, met the model performance criterion.

8.2 Future Model Runs

Before its presentation and application in the Phase 2 RI, the FWM will be calibrated to optimize its ability to predict concentrations of PCBs in the tissues of target species. The calibration process will be conducted in consultation with EPA and Ecology. This section describes some of the key results and decisions to be made.

8.2.1 Choice of empirical dataset to evaluate model performance

As discussed in Section 3.1, several datasets are available to evaluate model performance (i.e., historical, Phase 2 [2004], Phase 2 [2005], and a combination of the datasets). Total PCB concentrations in tissue were consistently lower in historical data and data from 2005 compared to 2004 data (Table 3-3 and Figure 3-2). The preliminary results of the FWM presented in this memorandum were generally compared to the combined dataset, although the LDW-wide results were also compared to the 2004 and 2005 data separately.

The FWM performance, on an LDW-wide scale, was generally similar whether it was evaluated using the 2004 dataset or all datasets combined, potentially because the 2004 dataset is the largest dataset available. The model performance when compared to the 2005 dataset was similar to that for the combined datasets for shiner surfperch and English sole. However, the model-predicted total PCB concentrations for slender crab, Dungeness crab, and Pacific staghorn sculpin were higher than the empirical total PCB concentrations for those species in 2005 (with SPAFs ranging from 3.6 to 6.3). These results do not necessarily imply that the 2004 dataset is the most appropriate dataset for calibration. The dataset that will be used as the source of empirical data for calibration of the FWM will be determined through discussions with EPA and Ecology after completion of this memorandum.

8.2.2 Sensitive parameters to focus on for future calibration

One purpose of the sensitivity analyses was to develop a list of parameters ranked according to model sensitivity. Two types of sensitivity analyses were conducted. The first analysis was conducted by changing each input parameter 10% independently and assessing the impact on model output (i.e., predicted total PCB concentrations in tissue). The second analysis was conducted by running the FWM with reasonable upper- and lower-bound input parameter estimates separately and assessing the impact on model output.

The results of these analyses are presented in Table 8-1. In general, calibration will proceed by assessing the variability and uncertainty of each sensitive parameter. Parameters to which the model is sensitive, and which are highly uncertain, have the greatest potential to affect model predictions, while keeping parameter values within reasonable bounds.

Table 8-1. Ranking of the most sensitive input parameters for target species based on the results of the two sensitivity analyses

10% Sensitivity Analysis	Upper- and Lower-Bound Sensitivity Analysis
Most Sensitive Parameters for Target Species (and maximum SPD, absolute value)	Most Sensitive Parameters for Target Species (and maximum SPD, absolute value)
Dietary absorption efficiency of lipids (alpha) (24%)	Dietary absorption efficiency of lipids (alpha) (67%)
Water content (18%)	Dietary absorption efficiency of NLOM (beta) (54%)
Lipid density (17%)	Sediment PCB concentration (42%)
Food ingestion rate (G_D) (14%)	Lipid content (33%)
Lipid content (14%)	Weight (25%)
Dissolved oxygen (DO) (11%)	Lipid density (20%)
Water column temperature (10%)	Porewater, fraction ventilated (17%)
Dietary absorption efficiency of NLOM (beta) (9%)	Water column temperature (12%)
Sediment PCB concentration (8%)	Water PCB concentration (11%)
K_{OW} (7%)	β (MAF, proportionality constant for sorption capacity of NLOM) (11%)

8.2.3 Dietary scenarios

The sensitivity of the FWM and relative model performance to several plausible dietary scenarios was investigated for the five target species (Section 4.0). In general, predictions based on dietary scenario 2 most closely matched empirical data, except for Pacific staghorn sculpin, for which predictions based on dietary scenario 3 most closely matched empirical data.

Using the initial set of input values and dietary scenario 1, total PCB concentrations in tissues of Dungeness crab and Pacific staghorn sculpin were most overpredicted. These species are omnivores and both consume significant proportions of shrimp and juvenile crabs. Both species may also consume small/juvenile fish. The fact that both these species are being overpredicted using dietary scenario 1 may be related to either the designated fraction of juvenile fish in their diet or the fact that benthic invertebrates make a poor surrogate for shrimp and juvenile crabs. Dietary scenarios for these species in particular, and possibly for all target species, will be further investigated in future model runs.

8.2.4 Benthic invertebrate model compartment

Benthic invertebrates are one of the key prey species for the fish and crabs being modeled. Empirical tissue data are available for benthic invertebrates (a total of 20 subtidal and intertidal composite tissue samples). The collection of these data was not designed to provide a representative sampling of PCB concentrations in benthic invertebrate tissue throughout the LDW. Instead, the study was designed to sample various locations and to provide a sampling of the range of PCB concentrations in sediment. The data were collected in this manner to determine the relationship between total PCB concentrations in tissue and sediment through the use of an accumulation factor (or regression).

As a result, there are two different approaches to estimate representative concentrations of total PCBs in benthic invertebrate tissue: 1) using the mechanistic FWM, or 2) using the regression analysis in combination with a spatially weighted average total PCBs concentration in sediment for the LDW scale being evaluated. Both approaches to predicting representative PCB concentrations in benthic invertebrate tissue have uncertainties. Species-specific parameters for benthic invertebrates that could be calibrated in the FWM are diet (including sediment PCB concentrations as a surrogate dietary item), weight, lipid content, NLOM content, or fraction of porewater ventilated. Uncertainties in the regression analysis include sediment PCB concentration and extrapolation of point-by-point relationships between sediment and tissue to LDW-wide conditions.

The FWM is generally overpredicting the concentrations of total PCBs in fish and crabs (Table 3-2). Therefore, because of the uncertainties associated with values for benthic invertebrate input parameters in the FWM and the fact that the model is overpredicting total PCB concentrations in consumers of benthic invertebrates, the sediment-benthic invertebrate tissue regression (described in Appendix A, Section A.2.4) is recommended in place of the Arnot and Gobas benthic invertebrate model compartment for future model runs at the LDW-scale based on the current input values. When the FWM is run at the LDW-wide scale with benthic invertebrate tissue concentrations based on the regression approach, model predictions for all species are more similar to empirical data (Table 8-2). If smaller scales are preferred for certain target species, or if input parameters are changed significantly, this recommendation should be revisited to verify that it still optimizes model performance.

Table 8-2. Model results for LDW-wide scale with initial set of input values using sediment-tissue regression for benthic invertebrates

Species	Mean Empirical Total PCB Concentration in Tissue (µg/kg ww)	Model-Predicted Total PCB Concentration in Tissue (µg/kg ww)	% Difference[a]	Species Predictive Accuracy Factor[b]	Overprediction (+) or Underprediction (-)
Various phytoplankton	nd	47	na	na	na
Various zooplankton	nd	73	na	na	na
Benthic invertebrates	173	173	2%	1.0	+
Juvenile fish	nd	779	na	na	na
Slender crab	620	512	-17%	1.2	-
Dungeness crab	1,000	1,591	59%	1.6	+
Pacific staghorn sculpin	900	1,733	93%	1.9	+
Shiner surfperch	1,800	1,186	-34%	1.5	-
English sole	2,300	1,616	-30%	1.4	-
All Species					
Mean			12%	1.4	
Maximum			93%	1.9	
Minimum			-34%	1.0	

a Percent difference is the difference between the predicted and empirical tissue chemical concentrations divided by the empirical tissue chemical concentration.

b The SPAF is defined as the ratio of the predicted concentration divided by the empirical concentration if the predicted concentration is higher than the empirical concentration, and the reciprocal if the predicted concentration is lower than the empirical concentration.

na – not applicable

nd – no data

8.2.5 Choice of model scale

The FWM was run at two scales for this memorandum (LDW-wide and at the scale of modeling areas). The model will be run at the subarea scale for Pacific staghorn sculpin and shiner surfperch when EFCD model results are available.

Selection of the modeling scale for application in the RI will depend on model performance at a given scale. For example, the ability of the FWM to accurately predict concentrations of PCBs in fish and crab tissues at the LDW-wide scale relative to the ability of the model to accurately predict tissue concentrations when results of modeling at smaller scales are combined will be considered. Application of the FWM for the FS will depend on the scale at which the model provides the best predictive accuracy for the RI, as well as the specific remedial scenarios being evaluated in the residual risk assessment for the FS.

Based on the preliminary results presented in this memorandum (Tables 3-2 and 7-1), model performance generally does not appear to be significantly affected by the modeling scale when compared to the combined empirical dataset.

9.0 Next Steps

This memorandum is the third of the three memoranda prepared to document the development of the FWM. The preliminary results presented in this memorandum will be discussed with EPA, Ecology, and interested stakeholders in April, 2006. In addition, a number of steps will occur prior to the final documentation and application of the FWM in the Phase 2 RI/FS. These steps are listed below.

- **Step 1 - Selection of final SWAC for model runs.** By the end of April 2006, a final decision will be made on the method to be used to generate SWACs for total PCBs in the LDW. This method will be applied to calculate SWACs for total PCBs and OC_{sed} on an LDW-wide basis and for smaller spatial scales, as needed.
- **Step 2 - Recalibration of the EFDC model and decision on the need for additional water data.** In the spring of 2006, King County will be recalibrating the EFDC model using recently collected total PCB water data as well as updated sediment data. The model will predict total PCB concentrations in water for each cell in the model, allowing estimates of total PCB concentration in water at any scale to be modeled by the FWM. These data will be used to characterize the spatial variability of total PCB concentrations in surface water within the LDW. The EFDC model will also be able to provide temporal variability (intra-annual) information. Using the spatial variability information, the sensitivity of the FWM to EFDC-predicted total PCB concentration ranges in water will be tested. Based on these results, the need for additional water data will be determined by June 2006. If collection of additional water data is not considered necessary, the re-calibrated EFDC model predictions of total PCB concentrations in water will be used for future FWM runs.
- **Step 3 - Selection of most accurate and best-performing dietary scenario for each species.** Dietary scenarios (at the LDW-wide spatial scale) will be re-evaluated based on the results of these initial analyses and re-run using updated total PCB concentrations in sediment and water. Based on model performance and supporting dietary information, the most appropriate dietary scenario will be selected for each species.

- **Step 4 – Model runs with updated total PCB water column concentration and dietary scenarios.** The FWM will be re-run at various spatial scales using updated total PCB water and sediment concentrations and selected dietary scenarios for each species. In addition, after EFDC-predicted total PCB concentrations in water are available for each cell of the model in the LDW, average concentrations will be calculated for a subset of fish tissue sampling subareas. These concentrations will be used for FWM runs at a subarea scale for shiner surfperch and Pacific staghorn sculpin. The results of these runs will be discussed with EPA and Ecology to determine if additional calibration of the FWM is warranted to meet project needs.
- **Step 5 – Final documentation and application of the FWM.** After the FWM development is complete, it will be presented in the Phase 2 RI. In the RI, the FWM will be used to generate sediment quality thresholds based on risk-based goals for fish and crab tissue established in the ecological and human health risk assessments. In the FS, the FWM will be used as one tool to evaluate residual risks associated with various sediment cleanup alternatives.

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APPENDIX A. FOOD WEB MODEL PARAMETERS

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Appendix A. Food Web Model Parameters

This appendix presents the food web model (FWM) parameter values used for the Lower Duwamish Waterway (LDW)-wide and smaller spatial scale initial model runs. Section A.1 presents a summary of Arnot and Gobas (2004) specific model equations. Section A.2 presents parameter values derived using site-specific data. Section A.3 presents parameter values derived from the literature. Section A.4 presents parameter values used or cited in Arnot and Gobas (2004) or Gobas and Arnot (2005). Section A.5 presents parameter values specific to each fish and invertebrate species modeled.

A.1 Summary of Parameters

A summary of parameters in the Arnot and Gobas (2004) model are presented in Table A-1-1. The equations for the Arnot and Gobas (2004) model define environmental, biological, or chemical conditions or processes. The Arnot and Gobas model equations are presented in Table A-1-2. Parameter symbols within equations are defined in Tables A-2-1, A-3-1, and A-4-1.

Table A-1-1. Summary of Parameters

Parameter	Symbol	Origin	Table with Detailed Information
Algae, phytoplankton, and aquatic macrophytes – resistance to chemical uptake through aqueous phase	A	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Algae, phytoplankton, and aquatic macrophytes – resistance to chemical uptake through organic phase	B	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Bioavailable solute fraction	ϕ	calibrated in model	A-1-2
Chemical concentration in prey item *i*	$C_{D,i}$	calibrated in model	A-1-2
Chemical concentration in the modeled species	C_B	calibrated in model	A-1-2
Chemical concentration in the sediment, organic carbon normalized	$C_{S,OC}$	calibrated in model	A-1-2
Concentration of DOC in the water column	χ_{DOC}	site-specific empirical data	A-2-1
Concentration of POC in the water column	χ_{POC}	site-specific empirical data	A-2-1
Concentration of suspended solids in water column	C_{SS}	site-specific empirical data	A-2-1
Density of lipids	δ_Λ	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Density of water	δ_Ω	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Dietary absorption efficiencies of lipid	ε_L	default value from model application to the Great Lakes and San Francisco Bay	A-4-1

Parameter	Symbol	Origin	Table with Detailed Information
Dietary absorption efficiencies of NLOM/NLOC	ε_N	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Dietary absorption efficiencies of water	ε_W	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Dietary chemical transfer efficiency	E_D	calibrated in model	A-1-2
Disequilibrium factor for DOC partitioning	D_{DOC}	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Disequilibrium factor for POC partitioning	D_{POC}	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Dissolved oxygen concentration of water column	C_{OX}	site-specific empirical data	A-2-1
Fecal egestion rate	G_F	calibrated in model	A-1-2
Feeding rate	G_D	calibrated in model	A-1-2
Fraction of overlying water ventilated	m_O	derived from literature	A-3-1
Fraction of porewater ventilated	m_P	derived from literature	A-3-1
Fraction of the diet consisting of prey item *i*	P_i	derived from literature	A-3-1
Freely dissolved chemical concentration in the porewater	$C_{WD,P}$	calibrated in model	A-1-2
Freely dissolved chemical concentration in the water (total PCBs as Aroclors)	C_{WD}	calibrated in model	A-1-2
Gill ventilation rate	G_V	calibrated in model	A-1-2
Henry's Law Constant	H	derived from literature	A-3-1
Lipid content of organism	v_{LB}	site-specific empirical data	A-2-1
Lipid content of organism (zooplankton)	v_{LB}	derived from literature	A-3-1
Lipid content of phytoplankton/algae	v_{LP}	derived from literature	A-3-1
Lipid fraction of gut contents	v_{LG}	calibrated in model	A-1-2
Mean water column temperature	T	site-specific empirical data	A-2-1
NLOC content of phytoplankton/algae	v_{OCP}	derived from literature	A-3-1
NLOC fraction of gut contents	v_{OCG}	calibrated in model	A-1-2
NLOM content of organism	v_{NB}	site-specific empirical data	A-2-1
NLOM content of organism (zooplankton)	v_{NB}	derived from literature	A-3-1
NLOM fraction of gut contents	v_{NG}	calibrated in model	A-1-2
Octanol-water partition coefficient (total PCBs)	K_{OW}	derived from literature	A-3-1
Organic carbon-water partition coefficient	K_{OC}	calibrated in model	A-1-2
Organism-water partition coefficient on a wet weight basis	K_{BW}	calibrated in model	A-1-2
Overall lipid content of the diet	v_{LD}	calibrated in model	A-1-2
Overall NLOC content of the diet	v_{OCD}	calibrated in model	A-1-2
Overall NLOM content of the diet	v_{ND}	calibrated in model	A-1-2
Overall water content of the diet	v_{WD}	calibrated in model	A-1-2

PARAMETER	SYMBOL	ORIGIN	TABLE WITH DETAILED INFORMATION
Partition coefficient of the chemical between the contents of the gastrointestinal tract and the organism	K_{GB}	calibrated in model	A-1-2
Phytoplankton/algae-water partition coefficient on a wet weight basis	K_{PW}	calibrated in model	A-1-2
Proportionality constant describing similarity in phase partitioning of DOC relative to that of octanol	α_{DOC}	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Proportionality constant describing similarity in phase partitioning of POC relative to that of octanol	α_{POC}	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Proportionality constant expressing the sorption capacity of NLOC relative to that of octanol	β_{OC}	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Proportionality constant expressing the sorption capacity of NLOM relative to that of octanol	β	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Rate constant for aqueous uptake	k_1	calibrated in model	A-1-2
Rate constant for chemical elimination via excretion into egested feces	k_E	calibrated in model	A-1-2
Rate constant for chemical elimination via the respiratory area	k_2	calibrated in model	A-1-2
Rate constant for chemical uptake via the diet	k_D	calibrated in model	A-1-2
Rate constant for growth of aquatic organisms	k_G	calibrated in model	A-1-2
Rate constant for growth of phytoplankton/algae	k_G	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Rate constant for metabolic transformation of the chemical	k_M	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Respiratory surface chemical uptake efficiency	E_W	calibrated in model	A-1-2
Scavenging efficiency of particles absorbed from the water	σ	default value from model application to the Great Lakes and San Francisco Bay	A-4-1
Sediment OC content	OC_{sed}	site-specific empirical data	A-2-1
Total chemical concentration in the water column (Total PCBs as Aroclors)	C_{WT}	site-specific empirical data	A-2-1
Total chemical concentration in the sediment (Total PCBs as Aroclors)	C_S	site-specific empirical data	A-2-1
Water content of organism	v_{WB}	site-specific empirical data	A-2-1
Water content of organism (zooplankton)	v_{WB}	derived from literature	A-3-1
Water content of phytoplankton/algae	v_{WP}	derived from literature	A-3-1
Water fraction of gut contents	v_{WG}	calibrated in model	A-1-2
Weight of the organism	W_B	site-specific empirical data	A-2-1
Weight of the organism (zooplankton)	W_B	derived from literature	A-3-1

DOC – dissolved organic carbon
NLOC – non-lipid organic carbon
NLOM – non-lipid organic matter
OC – organic carbon
PCB – polychlorinated biphenyl
POC – particulate organic carbon

Table A-1-2. Equations for the Arnot and Gobas (2004) Model

PARAMETER	SYMBOL	UNITS	EQUATION	VALUE	NOTES	SOURCE
Biological						
Chemical concentration in the modeled species	C_B	µg/kg ww	$C_B = \{k_1 \times (m_O \times C_{WD} + m_P \times C_{WD,P}) + k_D \times \sum P_i \times C_{D,i}\} / (k_2 + k_E + k_G + k_M)$	species-specific model output	See Table A-2-4 for tissue chemistry data to be used to evaluate model performance.	Arnot and Gobas (2004)
Chemical concentration in prey item *i*	$C_{D,i}$	µg/kg ww	same as above	species-specific model output	See Table A-2-4 for tissue chemistry data to be used to evaluate model performance.	Arnot and Gobas (2004)
Rate constant for aqueous uptake (fish, invertebrates, and zooplankton)	k_1	L/kg·day	$k_1 = E_W \times G_V / W_B$	calculated in model using equation at left	For chemical uptake via the respiratory area (i.e., gills)	Gobas (1993); Gobas and MacKay (1987) as cited in Arnot and Gobas (2004)
Rate constant for aqueous uptake (algae, phytoplankton, and aquatic macrophytes)	k_1	L/kg·day	$k_1 = (A+(B/K_{OW}))^{-1}$	calculated in model using equation at left	For chemical uptake via the respiratory area (i.e., cell wall)	Arnot and Gobas (2004)
Rate constant for chemical elimination via the respiratory area	k_2	day^{-1}	$k_2 = k_1/K_{BW}$	calculated in model using equation at left	Loss through respiratory surface (gills or cell membrane/wall)	Gobas (1993) as cited in Arnot and Gobas (2004)
Rate constant for chemical uptake via the diet	k_D	kg food/kg organism·day	$k_D = E_D \times G_D / W_B$	calculated in model using equation at left	For phytoplankton/algae, k_D is zero.	Gobas (1993) as cited in Arnot and Gobas (2004)
Rate constant for chemical elimination via excretion into egested feces	k_E	day^{-1}	$k_E = G_F \times E_D \times K_{GB} / W_B$	calculated in model using equation at left	For phytoplankton/algae, k_E is zero.	Gobas et al. (1993) as cited in Arnot and Gobas (2004)
Rate constant for growth of aquatic organisms	k_G	day^{-1}	$k_G = 0.000502 \times W_B^{-0.2}$	calculated in model using equation at left	For temperatures around 10°C.	Thomann et al. (1992) as cited in Arnot and Gobas (2004)
Dietary chemical transfer efficiency	E_D	%	$E_D = (3.0 \times 10^{-7} \times K_{OW} + 2.0)^{-1}$	calculated in model using equation at left	Transfer of chemical across gut can be characterized by K_{OW} relationship.	Arnot and Gobas (2004)
Respiratory surface chemical uptake efficiency	E_W	%	$E_W = (1.85 + (155 / K_{OW}))^{-1}$	calculated in model using equation at left	Transfer of chemical across respiratory surface can be characterized by K_{OW} relationship.	Gobas (1988) as cited in Arnot and Gobas (2004)
Feeding rate – filter feeders	G_D	kg/d	$G_D = G_V \times Css \times \sigma$	calculated in model using equation at left		Morrison et al. (1996) as cited in Arnot and Gobas (2004)

PARAMETER	SYMBOL	UNITS	EQUATION	VALUE	NOTES	SOURCE
Feeding rate – other species	G_D	kg/d	$G_D = 0.022 \times W_B^{0.85} \times e^{(0.06 \times T)}$	calculated from weight of biota	Studies of feeding rates in cold-water fish (being used for zooplankton and aquatic invertebrate species as well).	Weiniger (1978) as cited in Arnot and Gobas (2004)
Fecal egestion rate	G_F	kg/d	$G_F = \{(1-\varepsilon_L) \times v_{LD}) + (1-\varepsilon_N) \times v_{OCD} + (1-\varepsilon_N) \times v_{ND} + (1-\varepsilon_W) \times v_{WD}\} \times G_D$	calculated in model using equation at left		Arnot and Gobas (2004)
Gill ventilation rate	G_V	L/d	$G_V = 1400 \times W_B^{0.65} / C_{OX}$	calculated in model using equation at left		Arnot and Gobas (2004)
Organism-water partition coefficient on a wet weight basis	K_{BW}	L water/kg biota	$K_{BW} = k_1/k_2 = v_{LB} \times K_{OW}/\delta_L + v_{NB} \times \beta \times K_{OW} + v_{WB}/\delta_W$	calculated in model using equation at left		Arnot and Gobas (2004)
Phytoplankton/algae-water partition coefficient on a wet weight basis	K_{PW}	L water/kg phytoplankton/algae	$K_{PW} = v_{LP} \times K_{OW}/\delta_L + \beta_{OC} \times v_{NP} \times K_{OW} + v_{WP}/\delta_W$	calculated in model using equation at left		Arnot and Gobas (2004)
Partition coefficient of the chemical between the contents of the gastrointestinal tract and the organism	K_{GB}	kg biota/kg digesta	$K_{GB} = (v_{LG} \times K_{ow}/\delta_L + v_{OCG} \times \beta_{OC} \times K_{ow} + v_{NG} \times \beta \times K_{ow} + v_{WG}/\delta_W) / (v_{LB} \times K_{ow}/\delta_L + v_{NB} \times \beta \times K_{ow} + v_{WB}/\delta_W)$	calculated in model using equation at left		Arnot and Gobas (2004)
Lipid fraction of gut contents	v_{LG}	kg lipid/kg digesta ww	$v_{LG} = (1-\varepsilon_L) \times v_{LD} / [(1-\varepsilon_L) \times v_{LD} + (1-\varepsilon_N) \times v_{OCD} + (1-\varepsilon_N) \times v_{ND} + (1-\varepsilon_W) \times v_{WD}]$	calculated in model using equation at left		Arnot and Gobas (2004)
NLOC fraction of gut contents	v_{OCG}	kg lipid/kg digesta ww	$v_{OCG} = [(1-\varepsilon_N) \times v_{OCD}] / [(1-\varepsilon_L) \times v_{LD} + (1-\varepsilon_N) \times v_{OCD} + (1-\varepsilon_N) \times v_{ND} + (1-\varepsilon_W) \times v_{WD}]$	calculated in model using equation at left	NLOC was added to the model to account for differential affinity of PCBs for NLOC (higher) as compared to NLOM	January 2006 update to Arnot and Gobas model (Arnot and Gobas 2004). Updated model, AQUAWEB, can be found on Environmental Toxicology Research Group website (Gobas 2006)
NLOM fraction of gut contents	v_{NG}	kg NLOM/kg digesta ww	$v_{NG} = (1-\varepsilon_N) \times v_{ND} / [(1-\varepsilon_L) \times v_{LD} + (1-\varepsilon_N) \times v_{OCD} + (1-\varepsilon_N) \times v_{ND} + (1-\varepsilon_W) \times v_{WD}]$	calculated in model using equation at left		Arnot and Gobas (2004)

Parameter	Symbol	Units	Equation	Value	Notes	Source
Water fraction of gut contents	v_{WG}	kg water/kg digesta ww	$v_{WG} = (1-\varepsilon_W) \times v_{WD} / [(1-\varepsilon_L) \times v_{LD} + (1-\varepsilon_N) \times v_{OCD} + (1-\varepsilon_N) \times v_{ND} + (1-\varepsilon_W) \times v_{WD}]$	calculated in model using equation at left		Arnot and Gobas (2004)
Overall lipid content of the diet	v_{LD}	kg lipid/kg food ww	$v_{LD} = \Sigma P_i \times v_{LB,i}$	calculated in model using equation at left		Arnot and Gobas model spreadsheet (Gobas 2006)
Overall NLOC content of the diet	v_{OCD}	kg NLOC/kg food ww	$v_{OCD} = P_P \times v_{OCP} + P_{sed} \times OC_{sed}$	calculated in model using equation at left	NLOC content of diet is determined by fraction of phytoplankton/algae and sediment consumed. These are the only dietary items with NLOC as a constituent.	January 2006 update to Arnot and Gobas model (Arnot and Gobas 2004). Updated model, AQUAWEB, can be found on Environmental Toxicology Research Group website (Gobas 2006)
Overall NLOM content of the diet	v_{ND}	kg NLOM/kg food ww	$v_{ND} = \Sigma P_i \times v_{NB,i}$	calculated in model using equation at left		Arnot and Gobas model spreadsheet (Gobas 2006)
Overall water content of the diet	v_{WD}	kg water/kg food ww	$v_{WD} = \Sigma P_i \times v_{WB,i}$	calculated in model using equation at left		Arnot and Gobas model spreadsheet (Gobas 2006)
Environmental						
Freely dissolved chemical concentration in the porewater	$C_{WD,P}$	µg/L	$C_{WD,P} = C_{S,OC} / K_{OC}$	calculated in model using equation at left	This parameter will be calculated for each spatial scale evaluated using sediment data appropriate for that spatial scale.	Kraaij et al. (2002) as cited in Arnot and Gobas (2004)
Chemical concentration in the sediment, organic carbon normalized	$C_{S,OC}$	µg/kg	$C_{S,OC} = C_S / OC_{sed}$	calculated in model using equation at left	This parameter will be calculated for each spatial scale evaluated, using sediment data appropriate for that spatial scale.	Calculated using Phase 1 and Phase 2 sediment data
Freely dissolved chemical concentration in the water (total PCBs as Aroclors)	C_{WD}	µg/L	$C_{WD} = (C_{WT} \times \phi)/1000$	calculated in model using equation at left	Simulates sequestering of chemical by DOC and POC in the water.	Arnot and Gobas (2004)
Bioavailable solute fraction	ϕ	unitless	$\phi = 1/(1 + \chi_{POC} \cdot D_{POC} \cdot \alpha_{POC} \cdot K_{OW} + \chi_{DOC} \cdot D_{DOC} \cdot \alpha_{DOC} \cdot K_{OW})$	calculated in model using equation at left	Simulates sequestering of chemical by DOC and POC in the water.	Arnot and Gobas (2004)

PARAMETER	SYMBOL	UNITS	EQUATION	VALUE	NOTES	SOURCE
Chemical						
Organic carbon-water partition coefficient	K_{OC}	L/kg	$K_{OC} = 0.35 \times K_{ow}$	calculated in model from equation at left	There are many different relationships established between K_{OW} and K_{OC}. This relationship was based on the analysis of a wide range of analytes (including PCB congeners) and soil/sediment matrices. The authors excluded data that may not have represented equilibrium conditions that can be very influential for high molecular weight PCBs. It is consistent with the commonly used approximation of $K_{oc} = 0.4\ K_{ow}$.	Seth et al. (1999)

DOC – dissolved organic carbon

NLOC – non-lipid organic carbon

NLOM – non-lipid organic matter

PCB – polychlorinated biphenyl

POC – particulate organic carbon

ww – wet weight

A.2 PARAMETERS DERIVED FROM SITE-SPECIFIC DATA

The LDW site-specific data presented in this section were derived from various field sampling events conducted in the LDW. Parameter names, symbols, units, selected values, comments, and source information for the initial set of parameters are presented in Table A-2-1. Parameters for which derivation of values cannot be fully explained within the limited space of a table are further discussed in the following subsections.

A.2.1 Sediment PCBs and OC_{sed}

Concentrations of total polychlorinated biphenyls (PCBs) (Aroclor sum) and organic carbon (OC_{sed}) in surface sediment data were derived from Phase 2 and historical (Phase 1) datasets according to "baseline" conditions, as described in the draft Technical Memorandum: Criteria for Defining the Baseline Surface Sediment Dataset for Use in the Lower Duwamish Waterway Phase 2 RI/FS (Windward 2006). Any changes to the baseline dataset will be reflected in the Phase 2 RI, where the final FWM results will be presented.

Table A-2-1. Model components with values determined using site-specific data

Parameter	Symbol	Units	Values – Mean (range)	No. of Samples	Notes	Source
Biological						
Weight of the organism	W_B	kg ww	species-specific	see Table A-2-3	see Table A-2-3	see Table A-2-3
Lipid content of organism	v_{LB}	% ww	species-specific	see Table A-2-3	see Table A-2-3	see Table A-2-3
Non Lipid Organic Matter (NLOM) content of organism	v_{NB}	% ww	species-specific	see Table A-2-3	See Table A-2-3. NLOM is a secondary site of PCB accumulation.	see Table A-2-3
Water content of organism	v_{WB}	% ww	species-specific	see Table A-2-3	See Table A-2-3. Water is not a significant contributor to the storage capacity of PCBs but is the third phase of storage in the body.	see Table A-2-3
Environmental						
Total PCB (as Aroclors) concentration in sediment (all LDW)	C_S	µg/kg dw	250	1,294	Spatially weighted average concentration calculated using IDW over the entire LDW	Calculated using baseline surface sediment data
Total PCB (as Aroclors) concentration in sediment (modeling area M1)	C_S	µg/kg dw	280	305	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M1.	Calculated using baseline surface sediment data.
Total PCB (as Aroclors) concentration in sediment (modeling area M2)	C_S	µg/kg dw	160	198	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M2.	Calculated using baseline surface sediment data.
Total PCB (as Aroclors) concentration in sediment (modeling area M3)	C_S	µg/kg dw	470	485	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M3.	Calculated using baseline surface sediment data.
Total PCB (as Aroclors) concentration in sediment (modeling area M4)	C_S	µg/kg dw	41	265	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M4.	Calculated using baseline surface sediment data.
Sediment OC content (all LDW)	OC_{sed}	% dw	1.93	1,294	Spatially weighted average concentration calculated using IDW over the entire LDW.	Calculated using baseline surface sediment data.

PARAMETER	SYMBOL	UNITS	VALUES – MEAN (range)	NO. OF SAMPLES	NOTES	SOURCE
Sediment OC content (modeling area M1)	OC_{sed}	% dw	2.00	305	LDW-wide, spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M1.	Calculated using baseline surface sediment data.
Sediment OC content (modeling area M2)	OC_{sed}	% dw	2.05	198	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M2.	Calculated using baseline surface sediment data.
Sediment OC content (modeling area M3)	OC_{sed}	% dw	1.75	485	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M3.	Calculated using baseline surface sediment data.
Sediment OC content (modeling area M4)	OC_{sed}	% dw	1.80	265	LDW-wide spatially weighted average concentration calculated using IDW over the entire LDW, but then clipped to M4.	Calculated using baseline surface sediment data.
Water						
Total chemical concentration in the water column (total PCBs as Aroclors)	C_{WT}	ng/L	2 (1.5 – 3.1)	King County samples (5 samples) = two stations, two depths, one event (with one field duplicate)	Model water scenarios will also be run using the following set of values: 1, 3, 5, and 10. PCB water mean has one significant figure due to uncertainty and low sample size.	Data received from King County (unpublished) (Williston 2005) for August 2005 sampling event, sample locations and collection methods are in the sampling and analysis plan (King County 2005)
Dissolved oxygen concentration of water column	C_{OX}	mg/L	8.0 (6.4 – 9.6)	11	Average of two stations, two depths from King County data, for each month Jan – Nov 2005.	King County Water Quality Monitoring Program (marine) (Mickelson 2006)
Mean water column temperature	T	°Celsius	11.6 (8.1 – 14.7)	11	Average of two stations, two depths from King County data, for each month Jan – Nov 2005.	King County Water Quality Monitoring Program (marine) (Mickelson 2006)
Concentration of DOC in the water column	χ_{DOC}	kg/L	2.2×10^{-6} ($1.4 \times 10^{-6} – 4.0 \times 10^{-6}$)	11	Average of two stations, two depths from King County data, for each month Jan – Nov 2005.	King County Water Quality Monitoring Program (marine) (Mickelson 2006)

PARAMETER	SYMBOL	UNITS	VALUES – MEAN (range)	NO. OF SAMPLES	NOTES	SOURCE
Concentration of POC in the water column	χ_{POC}	**kg/L**	**2.9×10^{-7} ($9.3 \times 10^{-8} - 7.7 \times 10^{-7}$)**	**11**	**Calculated concentration (POC = TOC – DOC) Average of two stations, two depths from King County data, for each month Jan – Nov 2005.**	**King County Water Quality Monitoring Program (marine) (Mickelson 2006)**
Concentration of suspended solids in water column	C_{SS}	kg/L	4.6×10^{-6} (1.9×10^{-6} – 7.6×10^{-6})	11	Average of two stations, two depths from King County data, for each month Jan – Nov 2005.	King County Water Quality Monitoring Program (marine) (Mickelson 2006)

Bold text indicates that the model has been demonstrated to be sensitive to that parameter in the past (Arnot 2005).

DOC – dissolved organic carbon

dw – dry weight

EFDC – Environmental Fluid Dynamics Code

IDW – inverse distance weighting

LDW – Lower Duwamish Waterway

NLOM – non-lipid organic matter

OC – organic carbon

PCB – polychlorinated biphenyl

POC – particulate organic carbon

TOC – total organic carbon

WQA – water quality assessment

ww –wet weight

Table A-2-2. Tissue chemistry datasets used in the preliminary FWM

Sampling Event	Year	Species	Tissue Type	Number of Individuals per Composite Tissue Sample	N	Parameter	Source
LDW Phase 2	2005	Dungeness crab	edible meat	5	3	weight, percent lipids, percent solids, PCB Aroclors	Windward (2006 in prep)
			hepatopancreas	5	3		
		slender crab	edible meat	5	1		
			hepatopancreas	10	1		
		English sole	whole body	5	11		
			paired skin-on fillet and remainder[a]	5	10		
		shiner surfperch	whole body	10	22		
		Pacific staghorn sculpin	whole body	10	4		
	2004	benthic invertebrates	whole body	> 100	20	weight, percent lipids, percent solids, community structure, PCB Aroclors	Windward (2005a, b)
		Dungeness crab	edible meat	5	7	weight, percent lipids, percent solids, PCB Aroclors, PCB congeners[b]	Windward (2005c, d)
			hepatopancreas	6 – 15	3		
		slender crab	edible meat	5	12		
			hepatopancreas	15 – 18	4		
		English sole	whole body	5	21		
		Pacific staghorn sculpin	whole body	7 – 10	24		
		shiner surfperch	whole body	9 – 10	24		
		starry flounder	whole body	5	3		
National Marine Fisheries Service (NMFS) Duwamish injury assessment project	2000	shiner surfperch	whole body	1	2	PCB Aroclors	NMFS (2002)

Sampling Event	Year	Species	Tissue Type	Number of Individuals per Composite Tissue Sample	N	Parameter	Source
King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay	1996 - 1997	Dungeness crab	edible meat	3	2	percent lipids, percent solids, PCB Aroclors	King County (1999)
			hepatopancreas	3	1		
		shiner surfperch	whole body	10	3		

[a] The remainder is the portion of fish that remains after removal of the skin-on fillet. These remainder and fillet data were used to estimate whole-body English sole concentrations as specified in the QAPP and the data report (Windward 2005f, 2006 in prep).

[b] The following composite samples were analyzed for PCB congeners: three Dungeness crab edible meat samples, two Dungeness crab hepatopancreas samples, five slender crab edible meat samples, two slender crab hepatopancreas samples, seven English sole whole-body samples, nine shiner surfperch whole-body samples, and eight Pacific staghorn sculpin whole-body samples.

N – Number of composite tissue samples analyzed

The total PCB sediment concentrations and OC_{sed} percentages used in the preliminary FWM runs were calculated from inverse distance weighting (IDW) interpolations derived from 1,294 surface sediment samples. The IDW parameters (e.g., search radius, weighting factor) were selected to optimize the ability of the IDW interpolation to predict concentrations of total PCBs in sediment where data are available for comparison. The optimized interpolation resulted in a predicted spatially weighted average concentration (SWAC) for total PCBs of 250 µg/kg dw and a spatially weighted average for total organic carbon (TOC) of 1.93% for the entire LDW (Table A-2-1).

Spatially weighted average concentrations and percentages for smaller spatial scales (modeling areas) were calculated using the same interpolation grids generated for the LDW-wide FWM spatial scale. The 10-ft by 10-ft squares from the IDW grid for each modeling area were selected, and spatially weighted average concentrations and percentages were calculated as the mean of all grid cells within a given modeling area of the LDW (Table A-2-1).

A.2.2 Water chemistry data

Water quality parameters with site-specific data include dissolved oxygen (DO), temperature, total suspended solids (TSS), dissolved organic carbon (DOC) and particulate organic carbon (POC), and total PCB concentrations (PCB congener sum). The particulate organic carbon (POC) was estimated from site-specific values for DOC and total organic carbon (TOC) in the water column. Values for these parameters were derived from 2005 data from the King County Marine Ambient and Outfall Water Column Monitoring Program (Mickelson 2006). In 2005, water samples were collected from two depths (1 m below the surface and 1 m above the sediment surface) at each of two stations in the LDW. The two stations were located just south of Harbor Island and at the 16th Avenue Bridge (King County 2005). Samples were collected for analysis of conventional parameters (temperature, TSS, DOC, and POC) monthly from January through November for a total of 44 samples. Summary statistics for these 44 samples were calculated as follows. Concentrations in the bottom and surface water samples on each collection date were averaged for each of the two sample stations, resulting in 11 average monthly concentrations for each parameter at each station. The average monthly values for the two stations were averaged to estimate the "LDW-wide" average monthly value for each parameter. The mean, minimum, maximum, and standard deviation (SD) concentrations of conventional water quality parameters in Table A-2-1 were calculated directly from the river-wide, monthly average values.

Concentrations of total PCBs in the water column were derived from the 2005 King County Duwamish River, Elliott Bay, and Green River water column PCB congener survey (King County 2005). Water samples were collected from the locations and depths described above. The samples were analyzed for all 209 individual PCB congeners. Four sampling events occurred in 2005, with the goal of capturing two low-flow events (August and September) and two high-flow events (November and

December). Validated data are currently available only from the August sampling event.

A.2.3 Tissue data

All Phase 2 tissue data and historical whole-body data identified as acceptable for use in the Phase 2 RI (Windward 2005g) were used for the FWM (Table A-2-2). Lipid content, water content, and total PCB concentrations were calculated from composite samples. Weight data were derived from all individual specimens collected from the LDW in Phase 2 (2004 and 2005). Weight data for juvenile fish were based on individual shiner surfperch (≤ 80 mm) from both background and LDW locations.

Site-specific tissue data from the LDW were used to determine input parameter values for lipid content (V_{LB}), water content (V_{WB}), and weight (W_B) for crabs and fish (Tables A-2-1 and A-2-3). Site-specific tissue data were also used to evaluate FWM model results at various spatial scales by comparing empirical concentrations of total PCBs in fish and crabs to concentrations predicted by the FWM (Table A-2-4). Methods for estimating an average PCB tissue concentration for benthic invertebrates from site-specific data to be used in model performance evaluation are described in Section A.2.4.

Table A-2-3. Characteristics of the modeled species

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Phytoplankton/algae					
Lipid content (% ww)	0.12 (0.10 – 0.14)	27	False Creek, Burrard Inlet, Vancouver, BC	Three samples each of two species of macroalgae and the contents of a plankton tow at three locations in False Creek. Average of green and brown algae and phytoplankton. "Phytoplankton" tissue analyzed was a combination of phytoplankton and zooplankton (236-µm plankton tow net).[a] The range of values was calculated using the plausible value range approach developed for the sensitivity analysis using standard deviation given in paper.	Mackintosh et al. (2004)
NLOC content (% ww)	4.3 (3.4 – 5.2)	27	False Creek, Burrard Inlet, Vancouver, BC	Three samples each of two species of macroalgae and the contents of a plankton tow at three locations in False Creek. Average of green and brown algae and phytoplankton. Phytoplankton and algae carbon is an important organic chemical storage phase due to low lipid concentrations. Carbon rather than "matter" is used for phytoplankton/algae because it is a better predictor of organic chemical content (Mackintosh et al. 2004). The range of values was calculated using the plausible value range approach developed for the sensitivity analysis using standard deviation given in paper.	Mackintosh et al. (2004)
Water content (% ww)	95.6 (94.7 – 96.5)	27	False Creek, Burrard Inlet, Vancouver, BC	Water content is calculated as 100% – % lipid – % carbon. Not a true measure of water content because there are constituents other than lipid and carbon. The range of values was calculated using the ranges of lipids and NLOC.	Mackintosh et al. (2004)
Fraction of porewater ventilated	0	na	na	Phytoplankton live in water column and are not exposed to porewater. Some benthic algae may be exposed to porewater; however, this biota compartment is primarily representing prey for zooplankton, with a little algae consumed by English sole. Therefore, the algae component of this compartment is not modeled as having exposure to porewater.	
Zooplankton					
Weight (kg ww)	1.6×10^{-7} (8.8×10^{-8} – 2.3×10^{-7})	126	Puget Sound (Budd Inlet)	Twenty-one samples from six stations (over 12 months). Average dry weight mass of zooplankton with assumed 90% water content (zooplankton was composed primarily of crustaceans, cnidarians, larvaceans, and polychaetes).	Giles and Cordell (1998)
Lipid content (% ww)	1.2 (0.9 – 1.7)	nr	Maizura Bay, Japan	Converted from dry weight assuming 90% water content.	Kuroshima et al. (1987) as cited in Delbare et al. (1996)
NLOM content (% ww)	8.8 (7.1 – 12.1)	na	na	NLOM = 100% -% water - % lipids	calculated from water and lipid content

Table A-2-3, cont.

Parameter	Value – Mean (range)	Sample Size	Locale of Data Collection	Notes	Source
Water content (% ww)	90 (87-91.2)	nr	Maizura Bay, Japan	Samples collected over 5 months. Species collected not specified.	Kuroshima et al. (1987) as cited in Delbare et al. (1996)
Fraction of porewater ventilated	0	na	na	Zooplankton live in water column and are not exposed to porewater.	
Dietary Scenario 1 for zooplankton (fraction)					
Phytoplankton/algae	1	na	na	It is assumed that the proportion of carnivorous zooplankton in the LDW is insignificant compared to the proportion of herbivorous zooplankton.	
Benthic invertebrates					
Weight (kg ww) (all LDW)	5.1×10^{-5} (5.5×10^{-6} – 2.1×10^{-4})	10	LDW	Ten intertidal and ten subtidal samples; weight calculated as average number of individuals divided by sample mass using taxonomy samples from the subtidal zone only ("picked" classification). Weight data were not varied by area because of the uncertainty associated with this calculation (see Section A.2.5).	Phase 2 (2004) benthic invertebrate data
Lipid content (% ww) (all LDW)	0.89 (0.35 – 1.4)	20	LDW	ten intertidal and ten subtidal samples	Phase 2 (2004) benthic invertebrate data
Lipid content (% ww) (modeling area M1)	0.94 (0.69 – 1.3)	6	Area M1	two intertidal and three subtidal samples	Phase 2 (2004) benthic invertebrate data
Lipid content (% ww) (modeling area M2)	1.1 (0.79 – 1.4)	6	Area M2	three intertidal and three subtidal samples	Phase 2 (2004) benthic invertebrate data
Lipid content (% ww) (modeling area M3)	0.66 (0.35 – 1.1)	4	Area M3	two intertidal and two subtidal samples	Phase 2 (2004) benthic invertebrate data
Lipid content (% ww) (modeling area M4)	0.78 (0.62-0.95)	4	Area M4	two intertidal and two subtidal samples	Phase 2 (2004) benthic invertebrate data
Water content (% ww) (all LDW)	88.9 (83.4 – 95.9)	20	LDW	ten intertidal and ten subtidal samples	Phase 2 (2004) benthic invertebrate data
Water content (% ww) (modeling area M1)	87.5 (83.4 – 91.7)	6	Area M1	three intertidal and three subtidal samples	Phase 2 (2004) benthic invertebrate data
Water content (% ww) (modeling area M2)	86.9 (84.3 – 90.6)	6	Area M2	three intertidal and three subtidal samples	Phase 2 (2004) benthic invertebrate data
Water content (% ww) (modeling area M3)	91.9 (86.3 – 95.9)	4	Area M3	two intertidal and two subtidal samples	Phase 2 (2004) benthic invertebrate data
Water content (% ww) (modeling area M4)	90.5(89.3 – 92.4)	4	Area M4	two intertidal and two subtidal samples	Phase 2 (2004) benthic invertebrate data

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Fraction of porewater ventilated/ all exposure areas	0.20 (0.05 – 0.3)	na	na	Benthic invertebrates live on or in sediment and ventilate water just above sediment surface.	Winsor et al. (1990)
Dietary Scenario 1 for benthic invertebrates (fraction)					
Phytoplankton/algae	0.11 (0.01 – 0.16)	na		Many taxa have multiple feeding types; dominant feeding type for each taxa estimated using the literature. Feeding guilds were assigned to each phyla (subtidal samples only), and then percent feeding guild was assigned to each sample based on % weight. Average percent feeding guilds were calculated for all 10 samples. Because the model does not allow modeled species to have a fraction of their diet from their own model compartment, and because only one benthic invertebrate compartment was created, sediment was used as a surrogate for benthic invertebrate prey consumed by carnivores. A "detritus" compartment was not modeled because of a lack of data to generate values for such a compartment. Sediment was used as a surrogate for detritus consumed by deposit feeders. Diets were estimated assuming that carnivores consumed 100% sediment, suspension feeders consumed 30% zooplankton and 70% phytoplankton/algae, and deposit feeders consumed 100% sediment.	Literature review performed for feeding guilds of species identified in Phase 2 taxonomy samples
Zooplankton	0.05 (0.01 – 0.07)	na			
Sediment	0.84 (0.77 – 0.99)	na			
Dietary Scenario 2 for benthic invertebrates (fraction)					
Phytoplankton/algae	0.11 (0.01 – 0.16)	na		Many taxa have multiple feeding types; dominant feeding type for each taxa estimated using the literature. Feeding guilds were assigned to each phyla (subtidal samples only), and then percent feeding guild was assigned to each sample based on % weight. Average percent feeding guilds were calculated for all 10 samples. Because the model does not allow modeled species to eat themselves (i.e., have a fraction of their diet from their own model compartment), and because only one benthic invertebrate compartment was created, sediment was used as a surrogate for benthic invertebrate prey consumed by carnivores because of the similarities between total PCB concentrations in benthic invertebrate tissue and sediment. A "detritus" compartment was not modeled because of a lack of data to generate values for such a compartment. Sediment was used as a surrogate for detritus consumed by deposit feeders because it was assumed to have similar PCB concentrations. Assumed that carnivores consumed 50% sediment and 50% zooplankton, suspension feeders consumed 30% zooplankton and 70% phytoplankton/algae, and deposit feeders consumed 100% sediment.	Literature review performed for feeding guilds of species identified in Phase 2 taxonomy samples
Zooplankton	0.12 0.02 – 0.17)	na			
Sediment	0.77 (0.67 – 0.97)	na			

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Dungeness crab -- combined edible meat and hepatopancreas					
Weight (kg ww) (all LDW)	0.423 (0.096 – 1.130)	51	LDW	Mean of all individual whole crab specimens in composites.	Phase 2 (2004, 2005) Dungeness crab data
Weight (kg ww) (modeling area M1)	0.570 (0.169 – 1.130)	20	Area T1	Mean of all individual whole crab specimens in composites.	Phase 2 (2004, 2005) Dungeness crab data
Weight (kg ww) (modeling area M2)	na	na	na	No Dungeness crabs were found in Area 2.	na
Weight (kg ww) (modeling area M3)	0.381 (0.100 – 0.780)	20	Area T3	Mean of all individual whole crab specimens in composites.	Phase 2 (2004, 2005) Dungeness crab data
Weight (kg ww) (modeling area M4)	0.231 (0.096 – 0.502)	11	Area T4	Mean of all individual whole crab specimens in composites.	Phase 2 (2004, 2005) Dungeness crab data
Lipid content (% ww) (all LDW)	2.6 (1.4 – 5.4)	7	LDW	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Lipid content (% ww) (modeling area M1)	3.2 (1.7 – 5.4)	3	Area T1	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Lipid content (% ww) (modeling area M2)	na	na	na	No Dungeness crabs were collected from Area 2.	na
Lipid content (% ww) (modeling area M3)	1.8 (1.4 – 2.2)	2	Area T3	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) Dungeness crab data
Lipid content (% ww) (modeling area M4)	2.4 (1.9 – 2.9)	2	Area T4	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) Dungeness crab data
Water content (% ww) (all LDW)	82 (78 – 85)	7	LDW	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Water content (% ww) (modeling area M1)	81 (79 – 84)	3	Area T1	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Water content (% ww) (modeling area M2)	na	na	na	No Dungeness crabs were found in Area 2.	na
Water content (% ww) (modeling area M3)	83.1 (81.3 – 84.8)	2	Area T3	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) Dungeness crab data

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Water content (% ww) (modeling area M4)	81.3 (77.9 – 84.7)	2	Area T4	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) Dungeness crab data
Fraction of porewater ventilated	0.02 (0.01 – 0.03)	na	na	Dungeness crabs live on sediment surface and ventilate some water from just above sediment surface (also stir up sediments when foraging).	Winsor et al. (1990); Gobas and Wilcockson (2003)
Dietary Scenario 1 for Dungeness crab (fraction)					
Benthic invertebrates	0.63 (0.42 – 0.84)	369	Grays Harbor, WA	Average % index of relative importance of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates or fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Stevens et al. (1982)
Juvenile fish	0.37 (0.16 – 0.58)	369	Grays Harbor, WA	Average % index of relative importance of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Stevens et al. (1982)
Dietary Scenario 2 for Dungeness crab (fraction)					
Benthic invertebrates	0.16	369	Grays Harbor, WA	Average % of individual identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no juvenile crab and shrimp prey model compartments were created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Stevens et al. (1982)
Zooplankton	0.48	369	Grays Harbor, WA	Average % of individual identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no juvenile crab and shrimp prey model compartments were created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Stevens et al. (1982)
Juvenile fish	0.36	369	Grays Harbor, WA	Average % of individual identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no juvenile crab and shrimp prey model compartments were created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Stevens et al. (1982); Gotshall (1977)

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Dietary Scenario 3 for Dungeness crab (fraction)					
Benthic invertebrates	0.75	na	na	Synthesis of two open-water studies (1977) considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad 1983).	
Juvenile fish	0.15	na	na	Synthesis of two open-water studies (1982) considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad 1983).	
Sediment	0.10	na	na	Up to 50% sediment has been observed in stomach contents.	Stevens et al. (1982)
Dietary Scenario 4 for Dungeness crab (fraction)					
Benthic invertebrates	0.75	416	Humbolt Bay, CA, and in ocean near mouth of Mad River, CA	Average % of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 4 classifies crabs and shrimp as benthic invertebrates.	Gotshall (1977)
Juvenile fish	0.25	416	Humbolt Bay, CA, and in ocean near mouth of Mad River, CA	Average % of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 4 classifies crabs and shrimp as benthic invertebrates.	Gotshall (1977)
Slender crab – combined edible meat and hepatopancreas					
Weight (kg ww) (all LDW)	0.164 (0.112 – 0.260)	74	LDW	Mean of all individual specimens in composites	Phase 2 (2004, 2005) slender crab data
Weight (kg ww) (modeling area M1)	0.170 (0.120 – 0.260)	16	Area T1	Mean of all individual specimens in composites	Phase 2 (2004, 2005) slender crab data
Weight (kg ww) (modeling area M2)	0.170 (0.120 – 0.230)	40	Area T2	Mean of all individual specimens in composites	Phase 2 (2004, 2005) slender crab data
Weight (kg ww) (modeling area M3)	0.150 (0.110 – 0.210)	18	Area T3	Mean of all individual specimens in composites	Phase 2 (2004, 2005) slender crab data
Weight (kg ww) (modeling area M4)	na	na	Area T4	No slender crabs were collected from T4.	Phase 2 (2004, 2005) slender crab data
Lipid content (% ww) (all LDW)	1.1 (0.98 – 1.4)	5	LDW	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Lipid content (% ww) (modeling area M1)	0.98	1	Area T1	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Lipid content (% ww) (modeling area M2)	1.1 (0.98 – 1.4)	3	Area T2	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Lipid content (% ww) (modeling area M3)	1.0	1	Area T3	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Lipid content (% ww) (modeling area M4)	na	na	Area T4	No slender crabs were collected from T4.	Phase 2 (2004, 2005) slender crab data
Water content (% ww) (all LDW)	83.6 (82.5 -- 85.6)	5	LDW	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Water content (% ww) (modeling area M1)	82.9	1	Area T1	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Water content (% ww) (modeling area M2)	83.2 (82.5 -- 83.6)	3	Area T2	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Water content (% ww) (modeling area M3)	85.6	1	Area T3	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration).	Phase 2 (2004, 2005) slender crab data
Water content (% ww) (modeling area M4)	na	na	Area T4	No slender crabs were collected from T4.	Phase 2 (2004, 2005) slender crab data
Fraction of porewater ventilated	0.02 (0.01 – 0.03)	na	na	Slender crabs live on sediment surface and ventilate some water from just above sediment surface (also stir up sediments when foraging).	Winsor et al. (1990); Gobas and Wilcockson (2003)
Dietary Scenario 1 for slender crab (fraction)					
Benthic invertebrates	0.99	40	Hecate Strait, BC	% of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Bernard (1979)
Juvenile fish	0.01	40	Hecate Strait, BC	% of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Bernard (1979)
Dietary Scenario 2 for slender crab (fraction)					
zooplankton	0.12	40	Hecate Strait, BC	% of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Bernard (1979)

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Benthic invertebrates	0.87	40	Hecate Strait, BC	% of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Bernard (1979)
Juvenile fish	0.01	40	Hecate Strait, BC	% of individual identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, benthic invertebrates and fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment..	Bernard (2005)
Dietary Scenario 3 for slender crab (fraction)					
Benthic invertebrates	0.90	na	na	Synthesis of available dietary information	C. Jensen (1979);Bernard (1977)
Sediment	0.10	na	na	Based on their primarily benthic diet	
Juvenile Fish					
Weight (kg ww)	0.006 (0.004 – 0.007)	16	LDW, East Passage, and Blake Island	Mean of all individual ≤ 80 mm shiner surfperch specimens for which weight data were available.	Phase 2 (2004, 2005) shiner surfperch data
Lipid content (% ww)	2.5 (1.4 – 3.6)	49	LDW	Estimated assuming that lipids are lower than adult English sole and adult shiner surfperch lipids with range proportional to range observed in adults (on average +/- 45% of mean). Juvenile chinook 0.6 to 2.8 avg 1.4.	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww)	73.9 (69.6 – 77.2)	46	LDW	Calculated using Phase 2 shiner surfperch data.	Phase 2 (2004, 2005) shiner surfperch data
Fraction of porewater ventilated	0.01 (0.005-0.02)	na	na	Shiner surfperch live in water column and feed at sediment surface, English sole live on sediment surface and burrow into sediment.	
Dietary Scenario 1 for juvenile fish (fraction)					
Zooplankton	0.07 (0.00 – 0.15)	112	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in juvenile English sole and adult shiner surfperch stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.93 (0.85 – 1)	112	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in juvenile English sole and adult shiner surfperch stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979);Wingert et al. (1979)

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Dietary Scenario 2 for juvenile fish (fraction)					
Zooplankton	0.17 (0.00 – 0.57)	112	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in juvenile English sole and adult shiner surfperch stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.83 (0.43 – 1)	112	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in juvenile English sole and adult shiner surfperch stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 3 for juvenile fish (fraction)					
Zooplankton	0.05	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979), considering additional general juvenile shiner surfperch dietary information and considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983).	Gordon (1970); Bane and Robinson (1967); Boothe (1977); Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.85	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979), considering additional general juvenile shiner surfperch dietary information and considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983).	Gordon (1970); Bane and Robinson (1967); Boothe (1977); Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Sediment	0.10	na	na	Best professional judgment in consideration of benthic diet	
Shiner surfperch					
Weight (kg ww) (all LDW)	0.017 (0.002 – 0.047)	458	LDW	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) shiner surfperch data
Weight (kg ww) (modeling area M1)	0.018 (0.007 – 0.047)	119	Area T1	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) shiner surfperch data
Weight (kg ww) (modeling area M2)	0.017 (0.007 – 0.040)	119	Area T2	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) shiner surfperch data

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Weight (kg ww) (modeling area M3)	0.017 (0.011 – 0.041)	120	Area T3	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) shiner surfperch data
Weight (kg ww) (modeling area M4)	0.016 (0.007 – 0.042)	100	Area T4	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) fish and crab data
Lipid content (% ww) (all LDW)	4.6 (1.6 – 6.9)	49	LDW	Mean of all composite samples	Phase 1 and Phase 2 (2004, 2005) shiner surfperch data
Lipid content (% ww) (modeling area M1)	4.1 (1.6 – 6.2)	15	Area T1	Mean of all composite samples	Phase 1 and Phase 2 (2004, 2005) shiner surfperch data
Lipid content (% ww) (modeling area M2)	4.7 (2.5 – 6.0)	12	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Lipid content (% ww) (modeling area M3)	4.9 (3.1 – 6.9)	12	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Lipid content (% ww) (modeling area M4)	5.0 (3.0 – 6.9)	10	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww) (all LDW)	73.9 (69.6 – 77.2)	46	LDW	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww) (modeling area M1)	74.1 (70.4 – 76.5)	12	Area T1	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww) (modeling area M2)	74.4 (72.7 – 77.2)	12	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww) (modeling area M3)	73.5 (69.6 – 77.0)	12	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Water content (% ww) (modeling area M4)	73.6 (69.7 – 77.2)	10	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) shiner surfperch data
Fraction of porewater ventilated	0.01 (0.005 – 0.02)	na	na	Shiner surfperch live in water column and feed at sediment surface.	Gobas and Wilcockson (1977)
Dietary Scenario 1 for shiner surfperch (fraction)					
Zooplankton	0.14 0.00 – 0.38)	65	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Benthic invertebrates	0.86 (0.62 – 0.95)	65	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 2 for shiner surfperch (fraction)					
Zooplankton	0.21 (0.00 – 0.57)	65	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.79 (0.43 – 1)	65	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 3 for shiner surfperch (fraction)					
Zooplankton	0.10	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979), considering additional general juvenile shiner surfperch dietary information and considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983).	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.80	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979), considering additional general juvenile shiner surfperch dietary information and considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983).	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Sediment	0.10	na	na	Best professional judgment in consideration of benthic diet	
English sole					
Weight (kg ww) (all LDW)	0.198 (0.073 – 0.600)	245	LDW	Mean of all individual specimens in whole body composite samples	Phase 2 (2004, 2005) English sole data
Weight (kg ww) (modeling area M1)	0.171 (0.076 – 0.500)	67	Area T1	Mean of all individual specimens in whole body composite samples	Phase 2 (2004, 2005) English sole data
Weight (kg ww) (modeling area M2)	0.189 (0.088 – 0.525)	67	Area T2	Mean of all individual specimens in whole body composite samples	Phase 2 (2004, 2005) English sole data

Table A-2-3, cont.

Parameter	Value – Mean (range)	Sample Size	Locale of Data Collection	Notes	Source
Weight (kg ww) (modeling area M3)	0.216 (0.079 – 0.404)	70	Area T3	Mean of all individual specimens in whole body composite samples	Phase 2 (2004, 2005) English sole data
Weight (kg ww) (modeling area M4)	0.236 (0.073 – 0.600)	68	Area T4	Mean of all individual specimens in whole body composite samples	Phase 2 (2004, 2005) English sole data
Lipid content (% ww) (all LDW)	5.5 (2.6 – 8.7)	42	LDW	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Lipid content (% ww) (modeling area M1)	5.2 (3.1 – 6.8)	12	Area T1	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Lipid content (% ww) (modeling area M2)	6.4 (4.9 – 8.7)	12	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Lipid content (% ww) (modeling area M3)	5.0 (2.6 – 7.5)	12	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Lipid content (% ww) (modeling area M4)	5.4 (3.9 – 6.3)	6	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Water content (% ww) (all LDW)	75.0 (71.0 – 79.0)	42	LDW	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Water content (% ww) (modeling area M1)	75.5 (73.4 – 79.0)	12	Area T1	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Water content (% ww) (modeling area M2)	73.9 (71.4 – 76.9)	12	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Water content (% ww) (modeling area M3)	75.4 (73.4 – 78.8)	12	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Water content (% ww) (modeling area M4)	75.0 (74.0 – 76.2)	6	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) English sole data
Fraction of porewater ventilated	0.1 (0.05 – 0.2)	na	LDW	English sole feed at the sediment surface and burrow into the sediment.	(Gobas and Wilcockson 2003)
Dietary Scenario 1 for English sole (fraction)					
Phytoplankton/algae	0.08 (0.05 – 0.10)	135	central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.92 (0.90 – 0.95)	135	central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Fresh et al. (1979); Wingert et al. (1979)

Table A-2-3, cont.

Parameter	Value – Mean (range)	Sample Size	Locale of Data Collection	Notes	Source
Dietary Scenario 2 for English sole (fraction)					
Phytoplankton/algae	0.07 (0.05 – 0.10)	135	central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Fresh et al. (1979); Wingert et al. (1979)
Zooplankton	0.05 (0.00 – 0.09)	135	central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.88 (0.86 – 0.90)	135	central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, or benthic invertebrates. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 3 for English sole (fraction)					
Benthic invertebrates	0.90	na	na	Synthesis of two open-water studies (Fresh et al. 1979; Wingert et al. 1979) considering that, as an estuary, the LDW may have a more benthic dominated food web (Simenstad and Watson 1983)	Fresh et al. (1979); Wingert et al. (1979)
Sediment	0.10	na	na	Best professional judgment in consideration of benthic diet	Fresh et al. (1979); Wingert et al. (1979)
Pacific staghorn sculpin					
Weight (kg ww) (all LDW)	0.060 (0.013 – 0.227)	272	LDW	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Weight (kg ww) (modeling area M1)	0.065 (0.018 – 0.180)	67	Area T1	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Weight (kg ww) (modeling area M2)	0.067 (0.020 – 0.227)	67	Area T2	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data

Table A-2-3, cont.

Parameter	Value – Mean (range)	Sample Size	Locale of Data Collection	Notes	Source
Weight (kg ww) (modeling area M3)	0.058 (0.016 – 0.164)	70	Area T3	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Weight (kg ww) (modeling area M4)	0.050 (0.013 – 0.168)	68	Area T4	Mean of all individual specimens in composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Lipid content (% ww) (all LDW)	2.1 (1.2 – 2.7)	28	LDW	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Lipid content (% ww) (modeling area M1)	2.2 (1.8 – 2.4)	7	Area T1	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Lipid content (% ww) (modeling area M2)	2.2 (1.8 – 2.7)	7	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Lipid content (% ww) (modeling area M3)	1.8 (1.3 – 2.1)	7	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Lipid content (% ww) (modeling area M4)	1.9 (1.2 – 2.5)	7	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Water content (% ww) (all LDW)	79.0 (78.0 – 80.5)	28	LDW	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Water content (% ww) (modeling area M1)	78.6 (78.0 – 79.6)	7	Area T1	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Water content (% ww) (modeling area M2)	78.9 (78.0 – 80.3)	7	Area T2	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Water content (% ww) (modeling area M3)	79.2 (78.9 – 79.7)	7	Area T3	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Water content (% ww) (modeling area M4)	79.2 (78.3 – 80.5)	7	Area T4	Mean of all composite samples	Phase 2 (2004, 2005) Pacific staghorn sculpin data
Fraction of porewater ventilated	0.05 (0.02 – 0.1)	na	LDW	Pacific staghorn sculpin feed at the sediment surface and burrow into the sediment.	

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Dietary Scenario 1 for Pacific staghorn sculpin (fraction)					
Benthic invertebrates	0.56 (0.32 – 0.83)	133	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Juvenile fish	0.44 (0.17 – 0.68)	133	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 1 classifies crabs and shrimp as benthic invertebrates.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 2 for Pacific staghorn sculpin (fraction)					
Zooplankton	0.37 (0.29 – 0.50)	133	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Benthic invertebrates	0.19 (0.04 – 0.32)	133	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Juvenile fish	0.44 0.17 – 0.68)	133	north Puget Sound, central Puget Sound, Nisqually Reach	Average % total weight of identifiable prey in stomach contents classified as either phytoplankton/algae, zooplankton, benthic invertebrates, or fish. Scenario 2 classifies crabs and shrimp as zooplankton because no crab and shrimp prey model compartment was created and the zooplankton model compartment may provide a more realistic surrogate for the crabs and shrimps consumed as prey than the benthic invertebrate compartment.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Dietary Scenario 3 for Pacific staghorn sculpin (fraction)					
Zooplankton	0.25	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979) considering that, as an estuary, the LDW may have a more benthic dominated food web (Simenstad and Watson 1983); but crabs and shrimp have less sediment exposure than infaunal benthic invertebrates, therefore 25% of diet considered zooplankton.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)

Table A-2-3, cont.

PARAMETER	VALUE – MEAN (range)	SAMPLE SIZE	LOCALE OF DATA COLLECTION	NOTES	SOURCE
Benthic invertebrates	0.50	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979) considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983); but crabs and shrimp have less sediment exposure than infaunal benthic invertebrates, therefore 25% of diet considered zooplankton.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Juvenile fish	0.15	na	na	Synthesis of three open-water studies (Fresh et al. 1979; Miller et al. 1977; Wingert et al. 1979) considering that, as an estuary, the LDW may have a more benthic-dominated food web (Simenstad and Watson 1983).	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)
Sediment	0.10	na	na	Best professional judgment in consideration of benthic diet.	Miller et al. (1977); Fresh et al. (1979); Wingert et al. (1979)

LDW – Lower Duwamish Waterway

na – not available

NLOC – non-lipid organic carbon

nr – not reported

tbd – to be determined

ww – wet weight

[a] Based on the size of the mesh size, these samples would have consisted mostly of zooplankton and chain-forming phytoplankton.

Table A-2-4. Total PCB tissue concentrations in fish and invertebrate species to be used to evaluate model performance

Area Modeled	Total PCB Tissue Concentration (µg/kg ww)		No. of Composite Samples	Notes	Source
	Average	Range			
Benthic invertebrates					
All LDW	170	1) 60 – 1,400 2) 150 – 200	20	Average was estimated using surface sediment total PCBs SWAC of 250 µg/kg dw for the entire LDW and the tissue-sediment regression derived from 20 co-located benthic invertebrate tissue and surface sediment samples. Range 1 is based on 10 intertidal and 10 subtidal samples collected throughout the LDW. Range 2 is based on the 95% confidence interval on the mean (for the regression-estimated average tissue concentration).	Phase 2 (2004) benthic data (for range 1 data) Average and range 2 calculated from Phase 2 (2004) benthic tissue data and co-located sediment data, and Phase 1 and Phase 2 sediment data
Modeling area M1	180	1) 66 – 310 2) 150 – 210	6	Average was estimated using sediment total PCBs SWAC of 280 µg/kg dw in area M1 and the tissue-sediment regression derived from 20 co-located benthic invertebrate tissue and surface sediment samples. Range 1 is based on 3 intertidal and 3 subtidal samples collected in area M1. Range 2 is based on the 95% confidence interval on the mean (for the regression-estimated average tissue concentration).	Phase 2 (2004) benthic data (for range 1 data) Average and range 2 calculated from Phase 2 (2004) benthic tissue data and co-located sediment data, and Phase 1 and Phase 2 sediment data
Modeling area M2	150	1) 100 – 1,400 2) 130 – 170	6	Average was estimated using sediment total PCBs SWAC of 160 µg/kg dw in area M2 and the tissue-sediment regression derived from 20 co-located benthic invertebrate tissue and surface sediment samples. Range 1 is based on 3 intertidal and 3 subtidal samples collected in area M2. Range 2 is based on the 95% confidence interval on the mean (for the regression-estimated average tissue concentration).	Phase 2 (2004) benthic data (for range 1 data) Average and range 2 calculated from Phase 2 (2004) benthic tissue data and co-located sediment data, and Phase 1 and Phase 2 sediment data

Table A-2-4, cont.

Area Modeled	Total PCB Tissue Concentration (µg/kg ww)		No. of Composite Samples	Notes	Source
	Average	Range			
Modeling area M3	220	1) 99 – 1,400 2) 180 – 270	4	Average was estimated using sediment total PCBs SWAC of 470 µg/kg dw in area M3 and the tissue-sediment regression derived from 20 co-located benthic invertebrate tissue and surface sediment samples. Range 1 is based on 2 intertidal and 2 subtidal samples collected in area M3. Range 2 is based on the 95% confidence interval on the mean (for the regression-estimated average tissue concentration).	Phase 2 (2004) benthic data (for range 1 data) Average and range 2 calculated from Phase 2 (2004) benthic tissue data and co-located sediment data, and Phase 1 and Phase 2 sediment data
Modeling area M4	92	1) 60 – 110 2) 80 – 100	4	Average was estimated using sediment total PCBs SWAC of 41 µg/kg dw in area M4 and the tissue-sediment regression derived from 20 co-located benthic invertebrate tissue and surface sediment samples. Range 1 is based on 2 intertidal and 2 subtidal samples collected in area M4. Range 2 is based on the 95% confidence interval on the mean (for the regression-estimated average tissue concentration).	Phase 2 (2004) benthic data (for range 1 data) Average and range 2 calculated from Phase 2 (2004) benthic tissue data and co-located sediment data, and Phase 1 and Phase 2 sediment data
Dungeness crab – combined edible meat and hepatopancreas					
All LDW	980	420 – 1,900	7	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Modeling area M1	830	450 – 1,400	3	Based on average Phase 1 and Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 1 and Phase 2 (2004, 2005) Dungeness crab data
Modeling area M3	1,000	420 – 1,600	2	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) Dungeness crab data

Table A-2-4, cont.

Area Modeled	Total PCB Tissue Concentration (µg/kg ww)		No. of Composite Samples	Notes	Source
	Average	Range			
Modeling area M4	1,200	420 – 1,900	2	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) Dungeness crab data
Slender crab – combined edible meat and hepatopancreas					
All LDW	620	250 – 800	5	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) slender crab data
Modeling area M1	650	na	1	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) slender crab data
Modeling area M2	600	250 – 800	3	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) slender crab data
Modeling area M3	630	na	1	Based on average Phase 2 (2004, 2005) data. Whole body = (0.31 × hepatopancreas total PCB concentration) + (0.69 × edible meat total PCB concentration)	Phase 2 (2004, 2005) slender crab data
Shiner surfperch – whole body					
All LDW	1,800	350 – 18,000	51		Phase 1 and Phase 2 (2004, 2005) shiner surfperch data
Modeling area M1	970	350 – 1,800	15		Phase 1 and Phase 2 (2004, 2005) shiner surfperch data
Modeling area M2	2,800	660 – 18,000	12	Average is 1,400 µg/kg ww if the 2004 T2E 18,000-µg/kg ww sample is excluded	Phase 2 (2004, 2005) shiner surfperch data
Modeling area M3	2,700	700 – 8,800	12		Phase 2 (2004, 2005) shiner surfperch data

Table A-2-4, cont.

Area Modeled	Total PCB Tissue Concentration (µg/kg ww)		No. of Composite Samples	Notes	Source
	Average	Range			
Modeling area M4	840	540 – 2,100	12		Phase 1 and Phase 2 (2004, 2005) shiner surfperch data
English sole – whole body					
All LDW	2,300	610 – 4,700	42		Phase 2 (2004, 2005) English sole data
Modeling area M1	2,600	1,100 – 4,700	12		Phase 2 (2004, 2005) English sole data
Modeling area M2	2,900	1,600 – 4,200	12		Phase 2 (2004, 2005) English sole data
Modeling area M3	2,000	610 – 4,300	12		Phase 2 (2004, 2005) English sole data
Modeling area M4	1,400	910 – 1,800	6		Phase 2 (2004, 2005) English sole data
Pacific staghorn sculpin – whole body					
All LDW	900	430 – 2,800	28		Phase 2 (2004, 2005) sculpin data
Modeling area M1	720	580 – 860	7		Phase 2 (2004, 2005) sculpin data
Modeling area M2	750	620 – 1,300	7		Phase 2 (2004, 2005) sculpin data
Modeling area M3	1,400	590 – 2,800	7		Phase 2 (2004, 2005) sculpin data
Modeling area M4	730	430 – 1,300	7		Phase 2 (2004, 2005) sculpin data

LDW – Lower Duwamish Waterway

na – not applicable

PCB – polychlorinated biphenyl

Paired English sole fillet and remainder samples were used to derive concentrations of parameters in "whole-body" samples. Ten whole-body concentrations of lipid content, water content, and total PCB concentrations were estimated for English sole based on the relative weights and analyte concentrations in corresponding skin-on fillet and remainder tissues collected in 2005. These samples were collected to calculate whole-body PCB concentrations as specified in the QAPP (Windward 2005f) and data report (Windward 2006 in prep).

Estimates of lipid content, water content, and total PCB concentrations were calculated for "whole body" crabs by combining the concentration in each composite hepatopancreas sample with concentrations in the corresponding edible meat composite samples (one or more samples) that were collected from the same crabs. Therefore, a single whole-body crab concentration was calculated for each of the 12 hepatopancreas samples in Table A-2-2.[1] Whole-body concentrations were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weights of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004.

Juvenile fish were modeled using shiner surfperch and English sole data to estimate input parameters. Juvenile shiner surfperch and juvenile starry flounder were the most abundant small fish (< 100 mm) captured in trawls during Phase 2 sampling conducted in late summer (Windward 2005c, 2006 in prep). For example, they represented 54 and 30% of the non-target catch, respectively, in the 2004 sampling event and 40 and 42%, respectively, in the 2005 sampling event. Thus, these species are likely prey for Pacific staghorn sculpin and crabs in the LDW. Because data for juvenile starry flounder and juvenile shiner surfperch were not available (with the exception of limited weight data), data from composite samples of adult shiner surfperch and English sole[2] were used. As noted in section A.2.3 and Table A-2-3, empirical weights for juvenile shiner surf perch were used as the basis for estimates of juvenile fish weight for the model.

All data for a given species were combined to determine the average, standard deviation, and range of total lipids, total solids, and total PCB concentrations. Averaging in this way reasonably represents populations foraging throughout the LDW because, for each species, the number of samples is fairly uniform throughout the LDW (Table A-2-5). The relatively even distribution of the data is demonstrated by dividing the LDW into four sections (M1 to M4), and summing the available tissue composite samples per section.

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[1] A total of 11 moisture content values were calculated because total solids data were not available for the Phase 1 hepatopancreas and edible meat samples.

[2] English sole and starry flounder are closely related (and produce viable offspring) so English sole are a reasonable surrogate for starry flounder. The English sole data includes three starry flounder composite samples from tissue sampling area T4.

Table A-2-5. Number of composite tissue samples available from each LDW modeling area

Species	Area	Number of Composite Tissue Samples
Benthic invertebrates	M1	6
	M2	6
	M3	4
	M4	4
English sole (whole body and estimated whole body[a])	M1	12
	M2	12
	M3	12
	M4	6
Pacific staghorn sculpin (whole body)	M1	7
	M2	7
	M3	7
	M4	7
Shiner surfperch (whole body)	M1	15
	M2	12
	M3	12
	M4	12(10)[c]
Dungeness crab (estimated whole body[b])	M1	3
	M2	0
	M3	2
	M4	2
Slender crab (estimated whole body[b])	M1	1
	M2	3
	M3	1
	M4	0

a Concentrations in 3 English sole whole-body composite samples in modeling areas M1, M2, and M3, and one composite sample in modeling area M4 were calculated as the weighted average of fillet and remainder composite samples.

b All whole-body crab concentrations were estimated as the weighted average of edible meat and hepatopancreas composite samples from the same crabs.

c Twelve composite samples were used to calculate total PCB concentrations; however, percent lipids and percent solids data were not available for the two Phase 1 samples.

Data from Phase 1 and Phase 2 (2004 and 2005) were combined to derive model input values. Percent lipids and percent solids whole-body tissue data from Phase 1 and Phase 2 (2004 and 2005) datasets are presented in Table A-2-6. One-way analysis of variance (alpha = 0.05) revealed statistically significant differences between 2004 and 2005 sampling events for Pacific staghorn sculpin percent lipids, and for shiner surfperch weight and percent solids. Pacific staghorn sculpin lipids were on average 24% higher in 2004 samples than 2005. However, 24 Pacific staghorn sculpin composite samples were collected in 2004 versus four samples collected in 2005.

When the four 2005 samples are compared using a paired t-test to the 2004 samples from the same subareas,[3] no statistically significant differences were observed.

Average shiner surfperch weight was 3 g higher in 2005 than in 2004 and average shiner surfperch total solids were 1.8% higher in 2005 than 2004. Because inter-annual variability in these parameters is expected, the variability in parameters between sampling events was considered to be representative of the variability in the data over the time period for which FWM predictions may apply. Variables that had statistically significant differences among sampling events will be given additional consideration during the calibration process, if needed. For the modeling-area scale, the average, standard deviation, and range for lipids and total solids were determined for each individual modeling area, whereas, weight parameter values were based on LDW-wide data (Table A-2-3).

[3] Each 2005 composite sample was paired with the 2004 composite sample from the same subarea.

Table A-2-6. Weight, percent lipids, and percent solids data used in the FWM for whole-body fish and crabs

Species	Analyte (units)	Phase 1		Phase 2 (2004)		Phase 2 (2005)	
		N	Average (SD)	N	Average (SD)	N	Average (SD)
English sole[a]	weight (g) [b]	nd	nd	140[b]	194 (90.6)	105[b]	204 (115)
	lipids (%)	nd	nd	21	5.8 (1.4)	21	5.22 (1.17)
	total solids (%)	nd	nd	21	25.0 (1.55)	21	25.1 (2.01)
Pacific staghorn sculpin	weight (g) [b]	nd	nd	232[b]	60.8 (32.7)	40[b]	55 (46)
	lipids (%)	nd	nd	24	2.1 (0.32)	4	1.65 (0.469)
	total solids (%)	nd	nd	24	21.1 (0.579)	4	20.6 (0.612)
Shiner surfperch	weight (g) [b]	nd	nd	238[b]	16 (5.7)	220[b]	19 (6.8)
	lipids (%)	3	2.8 (1.2)	24	3.9 (1.1)	22	5.74 (0.692)
	total solids (%)	nd	nd	24	24.7 (1.27)	22	27.6 (1.54)
Dungeness crab[c]	weight (g) [b]	nd	nd	36[b]	470 (280)	15[b]	302 (175)
	lipids (%)	1	5.4 (na)	3	2.3 (0.65)	3	1.98 (0.646)
	total solids (%)	nd	nd	3	19.0 (2.91)	3	17.0 (2.91)
Slender crab[c]	weight (g) [b]	nd	nd	64[b]	160 (29)	10[b]	190 (35.7)
	lipids (%)	nd	nd	4	1.1 (0.17)	1	0.980 (na)
	total solids (%)	nd	nd	4	16.1 (1.16)	1	17.5 (na)

a Ten of the 21 Phase 2 English sole composite samples were calculated as the weighted average of fillet and remainder composite samples.

b Weights were calculated using data for individual specimens rather than composites.

c Each whole-body crab lipid and total solids concentration was estimated by combining the concentration in the composite hepatopancreas sample with concentrations in the corresponding edible meat composite samples (one or more samples) that were collected from the same crabs. Therefore, a single whole-body crab concentration for each parameter was calculated for each composite hepatopancreas sample. Whole-body concentrations were calculated assuming 69% (by weight) edible meat and 31% hepatopancreas, based on the relative weight of these tissues in a 16.6-cm Dungeness crab dissected by Windward in 2004.

nd – no data

na – not applicable

SD – standard deviation

N – number of composite samples

A.2.4 Relationship between co-located benthic invertebrate tissue and surface sediment total PCB concentrations

Benthic invertebrate tissue and co-located surface sediment samples were collected from 20 locations in the LDW (10 intertidal locations and 10 subtidal locations). These locations were selected to provide a range of total PCB concentrations and spatial coverage throughout the LDW. These data were generated to evaluate whether there was a relationship between chemical concentrations in benthic invertebrate tissue and co-located sediment that could be applied in the FWM and exposure assessments for the risk assessments.

Linear least-squares regression was used to model the relationship between total PCB concentrations[4] in benthic invertebrate tissue and co-located sediment. The relationship between sediment and tissue was not linear and the residuals from a linear fit increased with the total PCB concentration in sediment. The log-log relationship provided a reasonable linear fit with homogeneous residuals (Figure A-2-1) [5] except for two extreme points (locations B5a-1 and B8a). Location B5a-1 had a low-moderate sediment PCB concentration and a very high tissue concentration. The sediment had very low organic carbon content, so this point was not extreme when the data were normalized. However, the normalized sediment relationship with tissue did not provide a good fit. Location B8a had a very high sediment concentration, but the tissue concentration was higher than would be predicted from a linear (log-log) relationship. This point was exerting undue influence on the regression estimates, and it was far higher than the concentrations for which tissue estimates were produced. The R^2 value with the outliers included was 0.51. Without these two points, the regression provided a good fit to the data in the range for which tissue concentrations will be predicted. The R^2 value with the outliers removed was 0.74. The regression parameters were estimated with full reporting-limit concentrations for the two non-detect samples.[6]

Figure A-2-1 displays the log-log linear relationship between PCB concentrations in co-located benthic invertebrate tissue and sediment. The equation for the line with outliers removed is presented as Equation A-2-1.

$$\log10[\text{tissue}] = 1.40 + 0.35 \times \log10[\text{sediment}] \qquad \textbf{Equation A-2-1}$$

Where:

[tissue] = total PCB concentration (µg/kg ww) in benthic invertebrate tissue
[sediment] = total PCB concentration (µg/kg dw) in sediment

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[4] The relationship between organic-carbon-normalized sediment and lipid-normalized tissue was also tested, but the total PCB relationship without normalization provided a better fit to the data.

[5] The regression analysis was conducted by Alice Shelly of Terrastat Consulting Group.

[6] There was one non-detect sediment concentration (B1a; reporting limit = 20 µg/kg dw) and one non-detect tissue concentration (B4a; reporting limit = 200 µg/kg ww).

Total PCB concentrations in benthic invertebrate tissues for the entire LDW and for each modeling area (Table A-2-4) were estimated from total PCBs in sediment using the equation above. The sediment concentrations used were the SWACs from corresponding areas of the LDW (Table A-2-1).

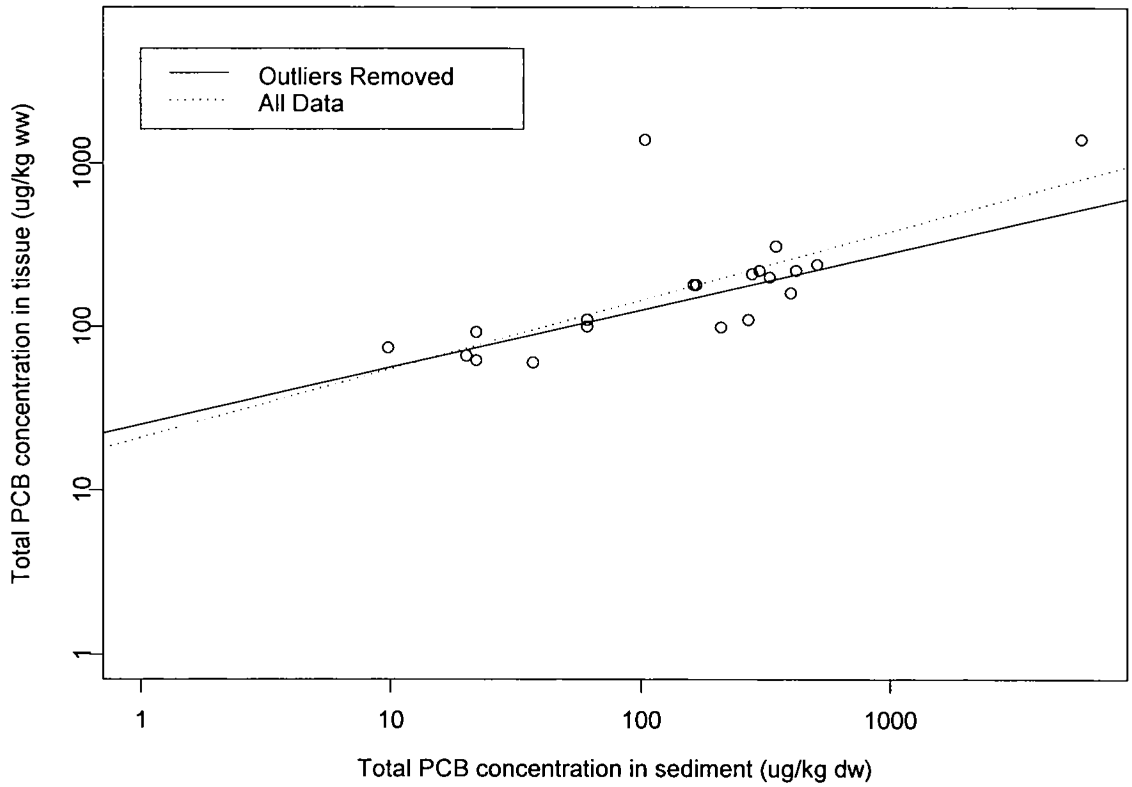

Figure A-2-1. Linear least-squares fit to log-transformed total PCB concentration in benthic invertebrate tissue as a function of log-transformed total PCB concentration in sediment

A.2.5 Benthic Invertebrate taxonomy data

Benthic community data from both benthic invertebrate taxonomy and tissue samples were used to estimate benthic invertebrate weights and diets (Table A-2-3). Derivations of these parameter values are discussed separately below.

Benthic invertebrate weights

Individual weights of benthic invertebrates were not measured as part of the laboratory processing of tissue or taxonomy samples. Therefore, an average individual weight was estimated using Phase 2 taxonomy abundance data and chemistry sample weight data (Windward 2005b, d). An average individual weight was estimated for each of the 10 subtidal locations based on the major taxonomic groups identified in co-located taxonomy and tissue samples. Several assumptions and data evaluation steps were needed to derive the average and range of weights, as described below.

- Very small invertebrates identified in the taxonomy samples were not included in the composite tissue samples because taxonomy samples were sorted using a microscope whereas the composite tissue samples were sorted using the naked eye. Based on the size of organisms in the site-specific taxonomic reference collection, invertebrates in each of the composite tissue samples were classified as picked, maybe picked, and not picked. This classification assumed that the majority of invertebrates in the samples were adults because juvenile benthic invertebrates are generally too small to see without a microscope. Those invertebrates classified as "picked" were assumed to be included in the composite tissue samples.
- The abundances and composition of taxa observed in the three taxonomy samples were assumed to be proportional to the number collected in the 20 composite tissue samples, e.g., if 10% of the invertebrates in a taxonomy sample were *A. salmonis,* then 10% of the invertebrates in the co-located tissue sample were assumed to be *A. salmonis.*
- The assumption of proportional similarity between taxonomy and composite tissue samples was carried one step further by assuming that if, for example, *A. salmonis* constituted 10% of the crustacean abundance in the taxonomy sample then they also constituted 10% of the crustacean weight in the co-located tissue sample. Implicit in this assumption was that all organisms within a major taxonomic group (i.e., Annelida, Crustacea, Mollusca, and Miscellaneous Phyla) weighed the same.
- A weight per organism in each major taxonomic group was calculated by relating the number of individuals in each major taxonomic group from taxonomy samples to the weights of each major taxonomic group from co-located tissue samples. Because more sediment grabs were required for tissue samples, the number of organisms in a given taxonomic group was multiplied by the factor difference between the number of taxonomy sample sediment grabs and tissue chemistry sample sediment grabs. For example, for location B-1b, three sediment grabs were included in the taxonomy sample and 11 grabs were included in the co-located tissue sample resulting in a factor difference of 3.67. Therefore, for this location, 188 annelids, assumed picked in the taxonomy sample, resulted in 689 annelids assumed to be present in the co-located tissue sample. The total number of organisms in a major taxonomic group was then divided by the weight data for that group from the tissue sample to determine the weight per organism. Thus, for location B1-b, a total

annelid weight of 7.4 g in the tissue sample was divided by 689 annelids, resulting in 0.011 g per annelid.

- For a given sample location, the average individual weights of each major taxonomic group were averaged (average of annelids, crustaceans, mollusks, and miscellaneous phyla) to arrive at an average individual weight for that sample location. These averages were then used to generate average, maximum, and minimum individual weights for benthic invertebrates (Table A-2-3).

Benthic invertebrate dietary scenarios

In order to generate dietary scenarios for benthic invertebrates, the following process was followed.

- "Picked" invertebrates observed in the subtidal taxonomy samples were assigned a feeding type based on literature review.[7] Feeding types included carnivore, deposit feeder,[8] herbivore, and suspension feeder. Combined feeding types were assigned if different feeding strategies were presented in the literature. Combined feeding types were assumed to participate in each feeding type equally, thus a deposit feeder/carnivore was assumed to be 50% deposit feeder and 50% carnivore.
- Weight and abundance data (using a "picked" classification of invertebrates) were then used to generate the percent of sample weight comprised of the different feeding types.
- Average, maximum, and minimum percent of each feeding type over the 10 subtidal sample locations were calculated.
- Each feeding type was then assigned percentages of available dietary items. For dietary scenario 1, deposit feeders were assumed to ingest 100% sediment, suspension feeders were assumed to ingest 30% zooplankton and 70% phytoplankton/algae, and carnivores were assumed to ingest 100% sediment. Because the model does not allow modeled species to have a fraction of their diet from their own model compartment, and because only one benthic invertebrate compartment was created, sediment was used as a surrogate for benthic invertebrate prey consumed by carnivores. A "detritus" compartment was not modeled because data are unavailable to generate values for such a compartment. Sediment was used as a surrogate for detritus consumed by

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[7] Not all benthic invertebrates were assigned a feeding group because of limited information in the literature.

[8] Detritivore and deposit feeding types were combined into one type (deposit feeder) because of the similarity of their food items, sediment and detritus. Differences in proportions of sediment versus detritus consumed between these two feeding types are insignificant because detritus is represented by sediment in the model.

deposit feeders because it was assumed to have similar PCB concentrations. A limitation of this assumption is that detritus has higher organic matter content than sediment and could potentially have higher PCB concentrations. Assumptions for dietary scenario 2 were the same except that carnivores were assigned to ingest 50% sediment and 50% zooplankton.

- Dietary item percentages were then multiplied by the percentage feeding type (by weight) to come up with dietary fractions of sediment, zooplankton, and phytoplankton/algae in the benthic invertebrate diet, for both dietary scenarios.

A.2.6 Estimation of log K_{OW} for PCBs

Estimates of log K_{ow} were determined using site-specific tissue data. A concentration-weighted average log K_{OW} was calculated using Equation A-2-2 for each tissue sample where all 209 individual PCB congeners were analyzed (Windward 2005a, e). PCB congener-specific K_{OW}s were taken from Hawker and Connell (1988). Because there was little variability in concentration-weighted average log K_{OW}s among species (Table A-2-7), the average of the species-specific averages (6.62) was used in the FWM. All results will be used for the data distribution in the sensitivity and uncertainty analyses.

$$\text{Average}K_{OW} = \frac{\sum_{i=1}^{n} C_i \times K_{OWi}}{\sum C_i} \qquad \textbf{Equation A-2-2}$$

Where:

C_i - Concentration of PCB congener i
K_{OWi} - K_{OW} of PCB congener i
n - number of detected PCB congeners

Table A-2-7. Average log K_{OW}s for each modeled species derived using site-specific tissue data from the LDW

Species	N	Minimum	Maximum	Average
Benthic invertebrates	8	6.42	6.87	6.57
Dungeness crab	5[a]	6.54	6.74	6.64
Slender crab	7[b]	6.55	6.63	6.58
English sole	7	6.50	6.64	6.56
Shiner surfperch	9	6.42	6.95	6.69
Pacific staghorn sculpin	8	6.63	6.84	6.69
Average of all tissue types				6.62

a Three edible meat composite samples and two hepatopancreas composite samples.
b Five edible meat composite samples and two hepatopancreas composite samples.
N Number of whole-body composite tissue samples

A.3 PARAMETERS DERIVED FROM THE LITERATURE

The data presented in this section were derived from literature sources investigated by Windward. Parameter names, symbols, units, selected values, comments, and source information for the initial set of parameter values are presented in Table A-3-1. Species-specific diets based on literature data are presented in Table A-2-3. Because the analyses conducted to determine parameter values for modeled fish and crab species' diets cannot be fully described in Table A-3-1, they are further discussed in Section A.3.1.

Table A-3-1. Model components with values derived from the literature

Model Component	Symbol	Units	Values – Mean (range)	Notes	Source
Biological					
Fraction of the diet consisting of prey item *i*	P_i	fraction (unitless)	species-specific	see A-2-3	see Table A-2-3
Fraction of overlying water ventilated	m_O	fraction (unitless)	species-specific	see Table A-2-3	
Fraction of porewater ventilated	$\mathbf{m_P}$	**fraction** (unitless)	**species-specific**	**see Table A-2-3**	
Lipid content of phytoplankton/algae	$\mathbf{v_{LP}}$	**% lipid ww**	**see Table A-2-3**	**see Table A-2-3**	**see Table A-2-3**
NLOC content of phytoplankton/algae	$\mathbf{v_{OCP}}$	**% NLOC ww**	**see Table A-2-3**	**See Table A-2-3. NLOC is secondary site of PCB accumulation, for phytoplankton/algae.**	**see Table A-2-3**
Water content of phytoplankton/algae	v_{WP}	% water ww	see Table A-2-3	see Table A-2-3	see Table A-2-3
Weight of the organism (zooplankton)	$\mathbf{W_B}$	**kg ww**	**species-specific**	**see Table A-2-3**	**see Table A-2-3**
Lipid content of organism (zooplankton)	$\mathbf{v_{LB}}$	**% lipid ww**	**species-specific**	**see Table A-2-3**	**see Table A-2-3**
NLOM content of organism (zooplankton)	$\mathbf{v_{NB}}$	**% NLOM ww**	**species-specific**	**See Table A-2-3. NLOM is a secondary site of PCB accumulation, for zooplankton.**	**see Table A-2-3**
Water content of organism (zooplankton)	v_{WB}	% ww	species-specific	See Table A-2-3. Water is not a significant contributor to the storage capacity of PCBs but is the third phase of storage in the body.	see Table A-2-3
Chemical					
Octanol-water partition coefficient (total PCBs)	K_{OW}	unitless	**6.62 (6.42 – 6.95)**	**Weighted average of K_{OW} for individual PCB congeners detected in Phase 2 tissue samples (for species in Table A-2-3), weighted by congener concentration (not weighted by species)**	**K_{OW}s for each congener from *Hawker and Connell (1988)***
Henry's Law Constant	H	(Pa x m^3)/mol	43.3	This value cancels out in the model calculations.	Mackay et al. (1992)

Bold text indicates that the model has been demonstrated as sensitive to this parameter in the past (Arnot 2005).

mol – mole (6.022×10^{23} entities)
NLOC – non-lipid organic carbon
NLOM – non-lipid organic matter
Pa – Pascals (units of pressure)
PCB – polychlorinated biphenyl
ww – wet weight

A.3.1 Fish and crab dietary scenarios

One to four dietary scenarios were developed to explore the effect of different dietary assumptions on FWM predictions. The relative proportion of each prey item in modeled species' diets was determined from literature-reported stomach contents analyses. The studies used to characterize fish and crab diets are summarized in Table A-3-2. Dietary data were reported using various metrics. Biomass data were preferred when available. From each study, all prey items constituting at least 1% of diet were assigned to one of the four prey categories used in the FWM: phytoplankton/algae, benthic invertebrates, zooplankton, and fish. Because some prey were unidentifiable, the percentage of prey biomass[9] assigned to each category was calculated relative to the total biomass of identifiable prey items only. The average fraction of prey biomass in each prey category over all studies was used to determine the relative proportions of prey used for FWM dietary scenarios 1 and 2 (Table A-2-3).[10] Juvenile fish diets were based on those of adult shiner surfperch because quantitative data for juveniles were not available. Juvenile English sole and shiner surfperch diets are similar, and diets are similar for between adult and juvenile life stages (Bane and Robinson 1970; Gordon 1965; Nyberg and Fahey 1988; Toole et al. 1987).

Table A-3-2. Dietary studies used to characterize modeled species' diets

Study	Species Modeled	Location	Habitat	Gear Types	Sampling Frequency	Reported Metrics
Miller et al. (1977)	shiner surfperch, Pacific staghorn sculpin	Multiple North Puget Sound locations (Canada border to Fidalgo Island)	eelgrass, cobble, gravel, kelp bed	tow net, trammel net, beach seine	seasonally	Biomass, %IRI
Fresh et al. (1979)	English sole, shiner surfperch, Pacific staghorn sculpin	Nisqually River estuary, Nisqually Reach	mud, sand, gravel	trawl, beach seine	monthly	Biomass, %IRI
Wingert et al. (1979)	English sole, shiner surfperch, Pacific staghorn sculpin	West Point, Alki Point, Point Pully	eelgrass (only Alki Point reported)	trawl, beach seine	monthly	Biomass, %IRI
Stevens et al. (1982)	Dungeness crab	Grays Harbor, WA	two locations – sand/mud-flat and not reported	trawl	seasonally	%IRI

9 Percent index of relative importance (%IRI) and % occurrence metrics were used for crab dietary studies.

10 Prey data from the two Dungeness crab studies were not averaged because they reported different dietary metrics.

STUDY	SPECIES MODELED	LOCATION	HABITAT	GEAR TYPES	SAMPLING FREQUENCY	REPORTED METRICS
Gotshall (1977)	Dungeness crab	Humbolt Bay, CA and nearby ocean	not reported	trawl	Nov to Dec, Aug to Sep	frequency of occurrence, percent of prey
Bernard (1979)	slender crab	Hecate Strait, BC	silt, sand, and gravel	trawl	August	% of individual prey items

%IRI – percent index of relative importance

For all species modeled, dietary scenarios 1 and 2 (and Dungeness crab scenario 4) were statistical estimates of the modeled species diets based solely on stomach contents analyses. Both scenarios used the same prey data, with crabs and shrimp reported as prey assigned to different prey categories. In dietary scenario 1 (and Dungeness crab dietary scenario 4),[11] all crabs and shrimp reported as prey were assigned to the benthic invertebrate category. However, for dietary scenario 2, all crabs and shrimp reported as prey were assigned to the zooplankton category. The percentages of prey in each of the four categories for dietary scenarios 1 (and Dungeness crab dietary scenario 4) are presented in Table A-3-3. The percentages of prey in each of the four categories for dietary scenario 2 are presented in Table A-3-4. Dietary scenario 3 is the only scenario assuming sediment consumption. The relative proportions of prey in dietary scenario 3 represents a synthesis of available information regarding each species' diet, combined with knowledge of the LDW estuarine community. The proportions of prey surrogates assumed for dietary scenario 3 are presented in Table A-2-3 and Table 4-1 of the main document.

[11] Because the two Dungeness crab studies report different metrics, one dietary scenario was developed for each study rather than averaging the dissimilar metrics to generate an average diet.

Table A-3-3. Percent of phytoplankton/algae, benthic invertebrates, zooplankton, and fish in all fish and crab species' diets for dietary scenario 1 (and Dungeness crab for dietary scenario 4)

Species	Study	Metric	N	Phyto-plankton/ Algae	Benthic Invertebrates	Zooplankton	Fish
Dungeness crab[a]	Stevens et al. (1982)[b]	%IRI	410	**0**	**63**	**0**	**37**
	Gotshall (1977)[c]	% occurrence	337	**0**	**75**	**0**	**25**
Slender crab[a]	Bernard (1979)	% occurrence	48	**0**	**99**	**0**	**1**
Shiner surfperch	Fresh et al. (1979)	biomass	10	0	62	38	0
	Miller et al. (1977)	biomass	24	0	100	0	0
	Wingert et al. (1979)	biomass	31	0	95	5	0
Average[b]				**0**	**86**	**14**	**0**
English sole	Fresh et al. (1979)	biomass	36	5	95	0	0
	Wingert et al. (1979)	biomass	99	10	90	0	0
Average[b]				**8**	**92**	**0**	**0**
Pacific staghorn sculpin	Fresh et al. (1979)	biomass	57	0	83	0	17
	Miller et al. (1977)	biomass	51	0	52	0	48
	Wingert et al. (1979)	biomass	25	0	32	0	68
Average[b]				**0**	**56**	**0**	**44**

[a] Crab studies were not averaged because different metrics were used to characterize diets.

[b] Data used in dietary scenario 1.

[c] Data used in dietary scenario 4.

Numbers in **bold** were used in the FWM.

%IRI – percent index of relative importance

N – number of stomachs analyzed

Table A-3-4. Percent of phytoplankton/algae, benthic invertebrates, zooplankton, and fish in all fish and crab species' diets for dietary scenario 2

SPECIES	STUDY	METRIC	N	PHYTO-PLANKTON/ ALGAE	BENTHIC INVERTEBRATES	ZOOPLANKTON	FISH
Dungeness crab	Stevens et al. (1982)	% IRI	410	**0**	**16**	**48**	**36**
Slender crab	Bernard (1979)	% occurrence	48	**0**	**87**	**12**	**1**
Shiner surfperch	Fresh et al. (1979)	biomass	10	0	43	57	0
	Miller et al. (1977)	biomass	24	0	100	0	0
	Wingert et al. (1979)	biomass	31	0	95	5	0
Average				**0**	**79**	**21**	**0**
English sole	Fresh et al. (1979)	biomass	36	5	86	9	0
	Wingert et al. (1979)	biomass	99	10	90	0	0
Average				**7**	**88**	**5**	**0**
Pacific staghorn sculpin	Fresh et al. (1979)	biomass	25	0	32	50	17
	Miller et al. (1977)	biomass	57	0	21	31	48
	Wingert et al. (1979)	biomass	51	0	4	29	68
Average				**0**	**19**	**37**	**44**

Numbers in **bold** were used in the FWM.

%IRI – percent index of relative importance

N – number of stomachs analyzed

A.4 DEFAULT PARAMETER VALUES FROM ARNOT AND GOBAS MODEL APPLICATION TO THE GREAT LAKES AND SAN FRANCISCO BAY

The data presented in this section were derived from development of the Arnot and Gobas model and its application to the Great Lakes (Arnot and Gobas 2004) and San Francisco Bay (Gobas and Arnot 2005). Parameter names, symbols, units, selected values, comments, and source information for the initial set of parameter values are presented in Table A-4-1.

Table A-4-1. Default values from Arnot and Gobas model application to the Great Lakes and San Francisco Bay

Model Component	Symbol	Units	Values – Mean (Range)	Notes	Source
Biological					
Density of lipids	δ_L	kg/L	0.9		
Rate constant for growth of phytoplankton/algae	k_G	day^{-1}	.08	Only phytoplankton/algae has k_G as an input number instead of an equation. This is a mean annual value based on empirical data in which slow-growth conditions (winter) were 0.03 day^{-1} and active-growth conditions (summer) were 0.13 day^{-1}.	Swackhamer and Skoglund (1993) as cited in Arnot and Gobas (2004)
Scavenging efficiency of particles absorbed from the water	σ	fraction	1	Used to calculate feeding rate for filter feeders.	Morrison et al. (1996); Reeders et al. (1989); Ten Winkel and Davids (1982) (as cited in Arnot and Gobas (2004))
Algae, phytoplankton, and aquatic macrophytes – resistance to chemical uptake through aqueous phase	A	day^{-1}	6×10^{-5} ($\pm 2.0 \times 10^{-5}$)	Derived from calibration to phytoplankton field BCF data from the Great Lakes.	Gobas and McLean (2003); Swackhamer and Skoglund (1993) (as cited in Arnot and Gobas (2004))
Algae, phytoplankton, and aquatic macrophytes – resistance to chemical uptake through organic phase	B	day^{-1}	5.5 (± 3.7)	Derived by calibration to empirical k_2 values from various freshwater phytoplankton, algae, and cyanobacteria species over a range of K_{OW} values.	Koelmans et al. (1993; 1995; 1999); Wang et al. (1996) (as cited in Arnot and Gobas (2004))
Proportionality constant expressing the sorption capacity of NLOM relative to that of octanol	β	L/kg	0.035	Based on 73-day lab test of HCBP with adult rainbow trout (*Oncorhynchus mykiss*) and a field study that analyzed PCB congener concentrations in tissue and GIT contents of rock bass (*Ambloplites rupestris*).	Gobas et al. (1999) (as cited in Arnot and Gobas (2004))
Proportionality constant expressing the sorption capacity of NLOC relative to that of octanol	β_{OC}	L/kg	0.35		Seth et al. (1999) (as cited in Arnot and Gobas (2004))

Model Component	Symbol	Units	Values – Mean (range)	Notes	Source
Dietary absorption efficiencies of lipid – fish	ε_L	**fraction**	**0.92**	**Based on 73-day lab test with adult rainbow trout (*Oncorhynchus mykiss*) and a field study of rock bass (*Ambloplites rupestris*).**	**Gobas et al. (1999) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of lipid – invertebrates	ε_L	**fraction**	**0.75**	**Based on studies involving zebra mussels from tidal freshwater section of Hudson River and polychaetes from Cape Cod intertidal flats.**	**Roditi and Fisher (1999); Berge and Brevik (1996); Gordon (1966); Parkerton (1993) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of lipid – zooplankton	ε_L	**fraction**	**0.72**	**Based on study involving *Calanus hyperboreus* eating diatoms and flagellates from Gulf of Maine.**	**Conover (1966) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of NLOM/NLOC – fish	ε_N	**fraction**	**0.6**	**Based on study with tetrachlorobiphenyl and rainbow trout.**	**Nichols et al. (2001) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of NLOM/NLOC – invertebrates	ε_N	**fraction**	**0.75**	**Based on studies involving zebra mussels from tidal freshwater section of Hudson River and polychaetes from Cape Cod intertidal flats.**	**Roditi and Fisher (1999); Berge and Brevik (1996); Gordon (1966); Parkerton et al. (1993) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of NLOM/NLOC – zooplankton	ε_N	**fraction**	**0.72**	***Calanus hyperboreus* eating diatoms and flagellates from Gulf of Maine.**	**Conover (1966) (as cited in Arnot and Gobas (2004))**
Dietary absorption efficiencies of water – all aquatic animal species	ε_W	fraction	0.55	This value has been increased from 25% for the Great Lakes to 55% due to marine conditions (marine organisms retain more water and produce concentrated urine).	Gobas and Arnot (2005)
Rate constant for metabolic transformation of the chemical	k_M	day^{-1}	0	Assume k_M to be zero for all PCBs. Arnot and Gobas (2003), Fisk et al. (2000), and Van der Linde et al. (2001) identify ways to calculate k_M.	Arnot and Gobas (2000)
Environmental					
Density of water	δ_W	kg/L	1.0		Weast et al. (1985)

Model Component	Symbol	Units	Values – Mean (range)	Notes	Source
Proportionality constant describing similarity in phase partitioning of DOC relative to that of octanol	α_{DOC}	unitless	0.08 (0.03 – 0.2)	Used in the bioavailable solute fraction equation for simulating sequestering of chemical by DOC in the water.	Burkhard (1999)
Proportionality constant describing similarity in phase partitioning of POC relative to that of octanol	α_{POC}	unitless	0.35 (0.14 – 0.87)	Used in the bioavailable solute fraction equation for simulating sequestering of chemical by POC in the water.	Seth et al. (2004)
Disequilibrium factor for DOC partitioning	D_{DOC}	unitless	1	Used in the bioavailable solute fraction equation for simulating sequestering of chemical by DOC in the water. Assumes chemicals in the water column are in equilibrium with DOC.	Arnot and Gobas (2004)
Disequilibrium factor for POC partitioning	D_{POC}	unitless	1	Used in the bioavailable solute fraction equation for simulating sequestering of chemical by POC in the water. Assumes chemicals in the water column are in equilibrium with POC.	Arnot and Gobas (2004)

Bold text indicates that the model has been demonstrated to be sensitive to this parameter in the past (Arnot 2005).

BCF – bioconcentration factor

DOC – dissolved organic carbon

GIT – gastrointestinal tract

HCPB – PCB 155

NLOM – non-lipid organic matter

PCB – polychlorinated biphenyl

POC – particulate organic carbon

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APPENDIX B. SENSITIVITY ANALYSES

Appendix B. Sensitivity Analyses

This appendix presents the backup information for the sensitivity analyses conducted for the food web model (FWM). The analysis of model sensitivity involves the investigation of how changes in input parameters affect model output and identifies parameters that most influence model predictions. This analysis provides the basis for determining calibration parameters and also for selecting parameters to be evaluated in the uncertainty analysis. As discussed in the main document, two types of sensitivity analyses were conducted: reducing the value of each input parameter by 10% and altering the value of each input parameter based on its plausible range. Both analyses assessed the model's sensitivity to changes in single parameters. However, the first analysis identified the parameters to which the model output was most sensitive only as a result of the mathematical structure of the model. The second analysis helped identify the parameters to which the model output was most sensitive as a result of both its mathematical structure and the potential variability in parameter values.

B.1 10 Percent Change Analysis

The 10% change analysis was conducted for all model input parameters identified in Table 5-1 of the FWM Memorandum 2 (Windward 2005) except three: the species-specific diet composition, the scavenging efficiency of particles absorbed from the water for filter feeders, and the concentration of suspended solids in the water column. The sensitivity of the model to differences in dietary composition was evaluated in Section 4.0 of the main document. Scavenging efficiency and suspended solids concentration were not included because they were not needed in the model. These parameters are used to calculate tissue concentrations for filter-feeding organisms, but filter feeders were not included in the current model because benthic invertebrates were modeled as scavengers / detritivores. The complete list of the 29 input parameters evaluated in the 10% change analysis and their initial and 10% adjusted values are presented in Table B-1-1.

All initial parameter values were decreased by 10% with the following exceptions: the octanol-water partition coefficient (K_{OW}) and the metabolic transformation rate of PCBs (k_M). Because K_{OW} is a component of many of the equations used in the model, the model is likely to respond differently to changes in K_{OW} depending upon which direction it is changed. Therefore, the model was run with both a 10% increase and decrease in K_{OW} to verify that it was not highly sensitive to a change in one direction but not the other. The initial k_M for PCBs was zero, which was not possible to decrease by 10%. Therefore, as discussed in FWM Memorandum 2 (Windward 2005), the model was run with a k_M of 0.0001 (Arnot 2005) and again with a 10% lower value (Table B-1-1).

Food ingestion rates (G_D), organism growth rates (k_G), and the PCB concentration of porewater are not actual input parameters in the model. They are all calculated from empirical equations within the model. For the 10% change analysis, their calculated values were decreased by 10%.

Table B-1-1. Input parameter values for sensitivity analyses

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
Environmental Parameters				
Total concentration of PCBs in the water column	ng/L	baseline	2	King County August water data (2005).
		-10%	1.8	
		upper (55%)	3.1	Full range of empirical data from August 2005 because too few data to calculate 95% confidence interval on the mean.
		lower (-25%)	1.5	Full range of empirical data from August 2005 because too few data to calculate 95% confidence interval on the mean.
Freely dissolved chemical concentration in the porewater ($C_{WD,P}$)	µg/kg	baseline	8.88×10^{-5}	Calculated in model based on the sediment concentration, OC_{sed}, and K_{OC}.
		-10%	7.99×10^{-5}	
		upper	na	Calculated in model; not possible to estimate a plausible range.
		lower	na	Calculated in model; not possible to estimate a plausible range.
Concentration of dissolved organic carbon (DOC) in the water column	kg/L	baseline	2.20×10^{-6}	Unpublished King County 2005 water data (Mickelson 2006).
		-10%	1.98×10^{-6}	
		upper (14%)	2.50×10^{-6}	95% confidence interval on the mean from King County 2005 data.
		lower (-18%)	1.80×10^{-6}	95% confidence interval on the mean from King County 2005 data.
Concentration of particulate organic carbon (POC) in the water column	kg/L	baseline	2.90×10^{-7}	Unpublished King County 2005 water data (Mickelson 2006). Calculated as TOC-DOC in water.
		-10%	2.61×10^{-7}	
		upper (41%)	4.10×10^{-7}	95% confidence interval on the mean from King County 2005 data.
		lower (-45%)	1.60×10^{-7}	95% confidence interval on the mean from King County 2005 data.
Mean water column temperature	°C	baseline	11.60	Unpublished King County 2005 water data (Mickelson 2006).
		-10%	10.44	
		upper (11%)	12.90	95% confidence interval on the mean from King County 2005 data.
		lower (-12%)	10.20	95% confidence interval on the mean from King County 2005 data.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
Dissolved oxygen concentration in the water column	mg/L	baseline	8	Unpublished King County 2005 water data (Mickelson 2006).
		-10%	7.2	
		upper (9%)	8.7	95% confidence interval on the mean from King County 2005 data.
		lower (-9%)	7.3	95% confidence interval on the mean from King County 2005 data.
Concentration of total PCBs in sediment	µg/kg dw	baseline	250	LDW-wide SWAC for baseline surface sediment data.
		-10%	225	
		upper (50%)	375	Based on a given range of results from the sediment groups investigation into different interpolation/SWAC generation methods
		lower (-50%)	125	Based on a given range of results from the sediment groups investigation into different interpolation/SWAC generation methods
Sediment organic carbon content (OC_{sed})	% dw	baseline	1.9	LDWG Phase 1 and 2 data.
		-10%	1.7	
		upper (6%)	2.04	Estimated value from 60th percentile of the distribution of estimates of the mean.
		lower (-8%)	1.78	Estimated value from 40th percentile of the distribution of estimates of the mean.
Proportionality constant describing similarity in phase partitioning of DOC relative to that of octanol (α_{DOC})	unitless	baseline	0.08	Arnot and Gobas (2004). Used to calculate bioavailable solute fraction in water in the model; resulting fraction = 0.464.
		-10%	0.072	Resulting bioavailable solute fraction = 0.480.
		upper (150%)	0.2	Arnot and Gobas (2004). Resulting bioavailable solute fraction = 0.307.
		lower (-63%)	0.03	Arnot and Gobas (2004). Resulting bioavailable solute fraction = 0.589.
Proportionality constant describing similarity in phase partitioning of POC relative to that of octanol (α_{POC})	unitless	baseline	0.35	Arnot and Gobas (2004). Used to calculate bioavailable solute fraction in water in the model; resulting fraction = 0.464.
		-10%	0.315	Resulting bioavailable solute fraction = 0.473.
		upper (149%)	0.87	Arnot and Gobas (2004). Resulting bioavailable solute fraction = 0.359.
		lower (-60%)	0.14	Arnot and Gobas (2004). Resulting bioavailable solute fraction = 0.526.
Disequilibrium factor for DOC partitioning (D_{DOC})	unitless	baseline	1.0	Arnot and Gobas (2004). Used to calculate bioavailable solute fraction in water in the model; resulting fraction = 0.464.
		-10%	0.9	Resulting bioavailable solute fraction = 0.480.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
		upper	na	Did not run; no range data available.
		lower	na	Did not run; no range data available.
Disequilibrium factor for POC partitioning (D_{POC})	unitless	baseline	1.0	Arnot and Gobas (2004). Used to calculate bioavailable solute fraction in water in the model; resulting fraction = 0.464.
		-10%	0.9	Resulting bioavailable solute fraction = 0.473.
		upper	na	Did not run; no range data available.
		lower	na	Did not run; no range data available.
Density of water (δ_W)	kg/L	baseline	1	Weast et al. (1985)
		-10%	0.9	
		upper	1.02	Weast et al. (1985)
		lower	na	
Chemical Parameters				
Octanol-water partition coefficient for PCBs (log K_{OW})	unitless	baseline	6.62	Phase 2 LDWG data and K_{OW} values in Hawker and Connell (1988).
		-10%	6.57	
		+ 10%	6.66	
		upper	6.66	95 % confidence interval on the mean for the LDWG data used above.
		lower	6.58	95 % confidence interval on the mean for the LDWG data used above.
Biological Parameters				
Density of lipids (δ_L)	kg/L	baseline	0.9	Arnot (2006)
		-10%	0.81	
		upper	1	
		lower	0.8	
Rate constant for metabolic transformation of PCBs (Km)	unitless	separate baseline	1×10^{-4}	Arnot (2005). In the initial set of input values Km = 0.
		-10%	9×10^{-5}	
		upper	na	
		lower	na	
Proportionality constant expressing the sorption capacity of NLOM	L/kg	baseline	0.035	Gobas et al. (1999), as cited in Arnot and Gobas (2004).
		-10%	0.0315	

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
relative to that of octanol (β or MAF)		upper (29%)	0.045	Arnot (2005)
		lower (-29%)	0.025	Arnot (2005)
Proportionality constant expressing the sorption capacity of NLOC relative to that of octanol (β_{OC})	L/kg	baseline	0.35	Seth et al. (1999)
		-10%	0.315	
		upper	na	
		lower	na	
Resistance to chemical uptake through aqueous phase for phytoplankton/algae (A)	day^{-1}	baseline	6.0×10^{-5}	Arnot and Gobas (2004)
		-10%	5.4×10^{-5}	
		upper (33%)	8.0×10^{-5}	Gobas and Arnot (2005)
		lower (-33%)	4.0×10^{-5}	Gobas and Arnot (2005)
Resistance to chemical uptake through organic phase for phytoplankton/algae (B)	day^{-1}	baseline	5.5	Arnot and Gobas (2004)
		-10%	4.95	
		upper (67%)	9.20	Gobas and Arnot (2005)
		lower (-67%)	1.80	Gobas and Arnot (2005)
Growth Rate Constant (k_G)				
Phytoplankton/algae	day^{-1}	baseline	8.00×10^{-2}	Model default = 0.8 (Arnot and Gobas 2004).
		-10%	7.20×10^{-2}	
Zooplankton	day^{-1}	baseline	1.15×10^{-2}	Calculated in model based on organism weight.
		-10%	1.03×10^{-2}	
Benthic invertebrates	day^{-1}	baseline	3.62×10^{-3}	Calculated in model based on organism weight.
		-10%	3.26×10^{-3}	
Juvenile fish	day^{-1}	baseline	1.40×10^{-3}	Calculated in model based on organism weight.
		-10%	1.26×10^{-3}	
Slender crab	day^{-1}	baseline	7.21×10^{-4}	Calculated in model based on organism weight.
		-10%	6.49×10^{-4}	
Dungeness crab	day^{-1}	baseline	5.96×10^{-4}	Calculated in model based on organism weight.
		-10%	5.37×10^{-4}	

Table B-1-1, cont.

Parameter	Units	Value Type (% change)	Value	Source
Pacific staghorn sculpin	day^{-1}	baseline	8.81×10^{-4}	Calculated in model based on organism weight.
		-10%	7.93×10^{-4}	
Shiner surfperch	day^{-1}	baseline	1.13×10^{-3}	Calculated in model based on organism weight.
		-10%	1.02×10^{-3}	
English sole	day^{-1}	baseline	6.94×10^{-4}	Calculated in model based on organism weight.
		-10%	6.25×10^{-4}	
Food Ingestion Rate (G_D)				
Zooplankton	kg food/ day	baseline	7.38×10^{-8}	Calculated in model based on organism weight and water temperature.
		-10%	6.64×10^{-8}	
Benthic invertebrates	kg food/ day	baseline	9.91×10^{-6}	Calculated in model based on organism weight and water temperature.
		-10%	8.92×10^{-6}	
Juvenile fish	kg food/day	baseline	5.70×10^{-4}	Calculated in model based on organism weight and water temperature.
		-10%	5.13×10^{-4}	
Slender crab	kg food/ day	baseline	9.49×10^{-4}	Calculated in model based on organism weight and water temperature.
		-10%	8.54×10^{-4}	
Dungeness crab	kg food/ day	baseline	2.12×10^{-2}	Calculated in model based on organism weight and water temperature.
		-10%	1.91×10^{-2}	
Pacific staghorn sculpin	kg food/ day	baseline	4.04×10^{-3}	Calculated in model based on organism weight and water temperature.
		-10%	3.63×10^{-3}	
Shiner surfperch	kg food/ day	baseline	1.38×10^{-3}	Calculated in model based on organism weight and water temperature.
		-10%	1.24×10^{-3}	
English sole	kg food/ day	baseline	1.11×10^{-2}	Calculated in model based on organism weight and water temperature.
		-10%	1.00×10^{-2}	
Organism Weight				
Zooplankton	kg	baseline	1.60×10^{-7}	Giles and Cordell (1998)
		-10%	1.44×10^{-7}	
		upper (44%)	2.30×10^{-7}	Range observed in literature.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
		lower (-45%)	8.80×10^{-8}	Range observed in literature.
Benthic invertebrates	kg	baseline	5.10×10^{-5}	LDWG Phase 2 data.
		-10%	4.59×10^{-5}	
		upper (312%)	2.10×10^{-4}	Range observed in LDWG Phase 2 data.
		lower (-89%)	5.50×10^{-6}	Range observed in LDWG Phase 2 data.
Juvenile fish	kg	baseline	6.00×10^{-3}	LDWG Phase 2 individual shiner surfperch specimens (<80mm) as surrogates for juvenile fish
		-10%	5.40×10^{-3}	
		upper (17%)	7.00×10^{-3}	95% confidence interval on LDWG Phase 2 data mean.
		lower (0%)	6.00×10^{-3}	95% confidence interval on LDWG Phase 2 data mean. Lower bound estimate comes out to be the same as the mean value due to rounding for significant figures.
Slender crab	kg	baseline	0.164	LDWG Phase 2 data.
		-10%	0.148	
		upper (5%)	0.172	95% confidence interval on LDWG Phase 2 data mean.
		lower (4%)	0.157	95% confidence interval on LDWG Phase 2 data mean.
Dungeness crab	kg	baseline	0.423	LDWG Phase 2 data.
		-10%	0.381	
		upper (55%)	0.657	95% confidence interval on LDWG Phase 2 data mean.
		lower (-77%)	0.096	Minimum observed from LDWG Phase 2; not possible to calculate lower confidence interval.
Pacific staghorn sculpin	kg	baseline	0.06	LDWG Phase 2 data.
		-10%	0.054	
		upper (7%)	0.0642	95% confidence interval on LDWG Phase 2 data mean.
		lower (-6%)	0.0562	95% confidence interval on LDWG Phase 2 data mean.
Shiner surfperch	kg	baseline	0.017	LDWG Phase 2 data.
		-10%	0.0153	
		upper (6%)	0.018	95% confidence interval on LDWG Phase 2 data mean.

Table B-1-1, cont.

Parameter	Units	Value Type (% change)	Value	Source
		lower (-2%)	0.0166	95% confidence interval on LDWG Phase 2 data mean.
English sole	kg	baseline	0.198	LDWG Phase 2 data.
		-10%	0.178	
		upper (7%)	0.211	95% confidence interval on LDWG Phase 2 data mean.
		lower (-7%)	0.185	95% confidence interval on LDWG Phase 2 data mean.
Lipid Content				
Phytoplankton/algae	% ww	baseline	0.1%	Mackintosh et al. (2004)
		-10%	0.1%	
		upper (16%)	0.1%	Range observed in literature.
		lower (-16%)	0.1%	Range observed in literature.
Zooplankton	% ww	baseline	1.2%	Kuroshima et al. (1987).
		-10%	1.1%	
		upper (42%)	1.7%	Range observed in literature.
		lower (-25%)	0.9%	Range observed in literature.
Benthic invertebrates	% ww	baseline	0.9%	LDWG Phase 2 data.
		-10%	0.8%	
		upper (12%)	1.0%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-14%)	0.8%	95% confidence interval on LDWG Phase 2 data mean.
Juvenile fish	% ww	baseline	2.5%	LDWG Phase 2 data for English sole and shiner surfperch.
		-10%	2.3%	
		upper (8%)	2.7%	Used the observed variability in means for English sole and shiner surfperch in LDWG Phase 2 data.
		lower (-8%)	2.3%	Used the observed variability in means for English sole and shiner surfperch in LDWG Phase 2 data.
Slender crab	% ww	baseline	1.1%	LDWG Phase 2 data.
		-10%	1.0%	
		upper (21%)	1.3%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-16%)	0.9%	95% confidence interval on LDWG Phase 2 data mean.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
Dungeness crab	% ww	baseline	2.6%	LDWG Phase 2 data.
		-10%	2.3%	
		upper (38%)	3.6%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-38%)	1.6%	95% confidence interval on LDWG Phase 2 data mean.
Pacific staghorn sculpin	% ww	baseline	2.1%	LDWG Phase 2 data.
		-10%	1.9%	
		upper (4%)	2.2%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-9%)	1.9%	95% confidence interval on LDWG Phase 2 data mean.
Shiner surfperch	% ww	baseline	4.6%	LDWG Phase 2 data.
		-10%	4.1%	
		upper (9%)	5.0%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-7%)	4.3%	95% confidence interval on LDWG Phase 2 data mean.
English sole	% ww	baseline	5.5%	LDWG Phase 2 data.
		-10%	5.0%	
		upper (7%)	5.9%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-7%)	5.1%	95% confidence interval on LDWG Phase 2 data mean.
Water Content				
Phytoplankton/algae	% ww	baseline	95.6%	Mackintosh et al. (2004).
		-10%	86.0%	
		upper (1%)	96.5%	Range observed in literature.
		lower (-1%)	94.7%	Range observed in literature.
Zooplankton	% ww	baseline	90.0%	Kuroshima et al. (1987).
		-10%	81.0%	
		upper (1%)	91.2%	Range observed in literature.
		lower (-3%)	87.0%	Range observed in literature.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
Benthic invertebrates	% ww	baseline	88.9%	LDWG Phase 2 data.
		-10%	80.0%	
		upper (2%)	90.4%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-2%)	87.3%	95% confidence interval on LDWG Phase 2 data mean.
Juvenile fish	% ww	baseline	73.9%	LDWG Phase 2 data.
		-10%	66.5%	
		upper (4%)	77.2%	Range observed in LDWG Phase 2 data.
		lower (-6%)	69.6%	Range observed in LDWG Phase 2 data.
Slender crab	% ww	baseline	83.6%	LDWG Phase 2 data.
		-10%	75.2%	
		upper (2%)	85.1%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-1%)	82.9%	95% confidence interval on LDWG Phase 2 data mean.
Dungeness crab	% ww	baseline	82.0%	LDWG Phase 2 data.
		-10%	73.8%	
		upper (2%)	83.9%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-3%)	79.5%	95% confidence interval on LDWG Phase 2 data mean.
Pacific staghorn sculpin	% ww	baseline	79.0%	LDWG Phase 2 data.
		-10%	71.1%	
		upper (0.3%)	79.2%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-0.3%)	78.8%	95% confidence interval on LDWG Phase 2 data mean.
Shiner surfperch	% ww	baseline	73.9%	LDWG Phase 2 data.
		-10%	66.5%	
		upper (1%)	74.5%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-1%)	73.3%	95% confidence interval on LDWG Phase 2 data mean.

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
English sole	% ww	baseline	75.0%	LDWG Phase 2 data.
		-10%	67.5%	
		upper (1%)	75.5%	95% confidence interval on LDWG Phase 2 data mean.
		lower (-1%)	74.4%	95% confidence interval on LDWG Phase 2 data mean.
Fraction of Porewater Ventilated				
Benthic invertebrates	fraction	baseline	0.2	Winsor et al. (1990).
		-10%	0.18	
		upper (25%)	0.25	Range observed in literature.
		lower (-75%)	0.05	Range observed in literature.
Juvenile fish	fraction	baseline	0.01	Gobas and Wilcockson (2003)
		-10%	0.009	
		upper (100%)	0.02	Range observed in literature.
		lower (-50%)	0.005	Range observed in literature.
Slender crab	fraction	baseline	0.02	Winsor et al. (1990); Gobas and Wilcockson (2003)
		-10%	0.018	
		upper	0.03	Range observed in literature.
		lower	0.01	Range observed in literature.
Dungeness crab	fraction	baseline	0.02	Winsor et al. (1990); Gobas and Wilcockson (2003)
		-10%	0.018	
		upper (50%)	0.03	Range observed in literature.
		lower (-50%)	0.01	Range observed in literature.
Pacific staghorn sculpin	fraction	baseline	0.05	Value from model components table.
		-10%	0.045	
		upper (100%)	0.1	Range from model components table.
		lower (-60%)	0.02	Range from model components table.
Shiner surfperch	fraction	baseline	0.01	Gobas and Wilcockson (2003)
		-10%	0.009	

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
		upper (100%)	0.02	Range observed in literature.
		lower (-50%)	0.005	Range observed in literature.
English sole	fraction	baseline	0.1	Gobas and Wilcockson (2003)
		-10%	0.09	
		upper (100%)	0.2	Range observed in literature.
		lower (-50%)	0.05	Range observed in literature.
Dietary Absorption Efficiency of Lipids (alpha)				
Zooplankton	fraction	baseline	0.72	Arnot and Gobas (2004)
		-10%	0.65	
		upper (18%)	0.85	Range reported in Arnot and Gobas (2004).
		lower (-42%)	0.55	Range reported in Arnot and Gobas (2004).
Benthic invertebrates (including crabs)	fraction	baseline	0.75	Arnot and Gobas (2004)
		-10%	0.68	
		upper (13%)	0.96	Range reported in Arnot and Gobas (2004).
		lower (-44%)	0.15	Range reported in Arnot and Gobas (2004).
All fish	fraction	baseline	0.92	Arnot and Gobas (2004)
		-10%	0.83	
		upper	na	No range data available.
		lower	na	No range data available.
Dietary Absorption Efficiency of NLOM (beta)				
Zooplankton	fraction	baseline	0.72	Arnot and Gobas (2004)
		-10%	0.65	
		upper (18%)	0.85	Range reported in Arnot and Gobas (2004).
		lower (-42%)	0.55	Range reported in Arnot and Gobas (2004).

Table B-1-1, cont.

PARAMETER	UNITS	VALUE TYPE (% change)	VALUE	SOURCE
Benthic invertebrates (including crabs)	fraction	baseline	0.75	Arnot and Gobas (2004)
		-10%	0.68	
		upper (13%)	0.96	Range reported in Arnot and Gobas (2004).
		lower (-44%)	0.15	Range reported in Arnot and Gobas (2004).
All fish	fraction	baseline	0.60	Arnot and Gobas (2004)
		-10%	0.54	
		upper (5%)	0.63	Assumed maximum based on values reported in Arnot and Gobas (2004).
		lower (-5%)	0.57	Reported in Arnot and Gobas (2004).
Dietary Absorption Efficiency of Water				
All organisms	fraction	baseline	0.55	Arnot and Gobas (2004)
		-10%	0.50	
		upper	na	No data were available to calculate a range.
		lower	na	No data were available to calculate a range.

Growth rate constant and food ingestion rate are calculated within the model; it was not possible to incorporate upper and lower range estimates.

na – not applicable

dw – dry weight

ww – wet weight

NLOC– Non-lipid organic carbon

NLOM – Non-lipid organic matter

SWAC – spatially weighted average concentration

B.2 PLAUSIBLE RANGE SENSITIVITY ANALYSIS

Upper- and lower-bound estimates were developed for all input parameters with significant information to estimate ranges. Plausible ranges were estimated for these parameters using one of two methods. A statistical method was used for parameters where enough data were available to determine the distribution of those data. This approach is described in detail in Section B.2.1. For both site-specific and literature-derived parameters with insufficient data to develop a distribution, range estimates were compiled from the literature. The methods used to determine the plausible range for each parameter are presented in Table B-1-1.

The following parameters were not included in the upper- and lower-bound sensitivity analysis because plausible value ranges were not available:

- Freely dissolved chemical concentration in the porewater
- Disequilibrium factor for dissolved organic carbon (DOC) partitioning
- Disequilibrium factor for particulate organic carbon (POC) partitioning
- Rate constant for metabolic transformation of PCBs (k_M)
- Growth rate constant (k_G)
- Food ingestion rate (G_D)
- Dietary absorption efficiency of lipids for fish
- Dietary absorption efficiency of water
- Concentration of suspended solids in the water column
- Scavenging efficiency of particles in the water column by filter feeders

B.2.1 Statistical approach

Mean data were generally used for the initial set of parameter values. The purpose of the plausible-range sensitivity analysis was to evaluate how sensitive the model was to expected or observed variability in the mean parameter values because of uncertainty or natural variability. Therefore, wherever possible, upper and lower estimates of the mean were used in this analysis. For parameters where data distribution information was available, the 95% confidence interval (CI) of the mean (i.e., the 2.5 and 97.5 percentiles of the distribution of estimates of the mean) was used to determine the plausible range. The statistical methods used depended on how the data for each parameter were distributed. The statistical analysis software ProUCL was used to determine how the data for each of these parameters was distributed and the statistical approach for calculation of confidence limits on the mean.

Most of the data were normally distributed. For those parameters, the 95% CI for the mean was approximated with the standard error (SE) using the following equations (Ott 1993):

$$SE = \text{Standard deviation}/\sqrt{(\text{sample number})}$$

$$95\%\ \text{CI of mean} = \text{mean} \pm (1.96 \times SE)$$

The same datasets that were used to determine initial parameter values (Appendix A) were used to estimate the plausible upper and lower ranges.

For data that were not normally distributed, ProUCL recommended another statistical approach to analyze the data. The methods recommended by ProUCL were, therefore, used to calculate the 95% CI of the mean.

For Dungeness crab weight, the data were not normally distributed. ProUCL provided a 97.5 upper confidence limit on the mean, but because larger crabs were selectively taken during sampling, the sample distribution was not expected to reflect population distribution for lower weights. For this reason, the minimum observed value was used as the lower range.

B.2.2 Literature-based approach

For those parameters with insufficient data about their distribution, range estimates were compiled from the literature. For most of these parameters, the ranges presented in the literature were used as the plausible ranges. Many of those ranges were presented in the model documentation (Arnot and Gobas 2004) and are included in the model components table (Appendix A).

As discussed in Appendix A, juvenile fish parameter values were calculated from the Phase 2 data for shiner surfperch and inferences from data in other studies (Gobas and Arnot 2005). The statistical approach described in Section B.2.1 was used to estimate the plausible range for juvenile fish weight and water content. Lipid content range, however, was estimated by applying the measured variability in lipid content from English sole and shiner surfperch (+/- 45% of the mean) to the calculated mean lipid content for juvenile fish.

There are few data directly addressing the dietary absorption efficiencies for lipids, non-lipid organic matter (NLOM), and water for various organisms, and they were not sufficient to provide estimates of the mean. Arnot and Gobas (2004) summarize the available data for all three parameters. Given the uncertainty around these parameter values, the full range of efficiencies for lipids and NLOM for all invertebrates were selected for zooplankton, benthic invertebrates, and crabs. No ranges were presented, however, for water absorption efficiencies for any species. Therefore, no plausible range estimates were used for that parameter.

Ranges were also not presented for the fish dietary absorption efficiencies for lipids and NLOM. Arnot and Gobas (2004) recommend using 60% for the NLOM absorption efficiency for fish, but the study they cite presents an NLOM absorption efficiency of 57% (Nichols et al. 2001). For the purposes of determining a plausible range in this analysis, 60% was used as the initial value and 57% was used as the lower range value. To be consistent with the lower range estimate and mean, and assuming estimates of the mean are normally distributed, 63% was assumed for an upper range estimate (Table B-1-1).

As discussed in Appendix A, the total PCB concentration in water was estimated using data collected from two stations in the LDW by King County (2005). When the sensitivity analysis was conducted, data were only available from the August sampling event. Consequently, there were insufficient data to determine a 95% CI on the mean for the total PCB concentration in the water column. The observed minimum and maximum concentrations reported in the model components table (Table A-2-1) were, therefore, used for the upper and lower plausible ranges.

As discussed in Appendix A, spatially weighted average concentrations (SWACs) of organic carbon (OC_{sed}) and total PCBs in sediment were estimated using an inverse distance weighting (IDW) interpolation model. It was not possible to estimate a meaningful plausible range for OC_{sed} content because the sample size generated by the interpolation model (187,000) was so large that the standard error estimates were not significant, given the number of significant figures for both OC_{sed} and total PCBs in sediment. Therefore, the 40th and 60th percentiles of the interpolated data distribution were assumed to represent plausible ranges of the mean OC_{sed} concentration (Table B-1).

The plausible range for the total PCB SWAC was estimated based on the previous efforts to develop a SWAC for sediment PCBs. Three different methods for determining an organic carbon (OC) normalized PCB SWAC (IDW, Thiessen Polygons, and Kriging) were investigated by LDWG in fall 2005, prior to the calculation of the SWAC using IDW as discussed in Section A.2.1 of Appendix A. The method that resulted in the highest SWAC (Thiessen Polygons) from these previous efforts differed by 50% from the IDW approach. The previous calculations included data through October 2005 and all PCB concentrations were OC normalized. The SWAC estimates were 18mg/kg-OC using Thiessen polygons, 12 mg/kg-OC using IDW, and 10 mg/kg-OC using Kriging. Assuming the ratio between estimates would be the same for OC normalized PCB concentrations as for bulk sediment PCB concentrations, SWAC estimates would be expected to span up to 1.5 times the mean concentration used in the FWM. Based on these analyses, the range around the selected SWAC of 250 µg/kg dw was estimated to be from 125 µg/kg dw to 375 µg/kg dw (Table B-1-1). The IDW interpolation approach and baseline sediment dataset were still being finalized at the time that this memorandum was being completed. Therefore, all SWAC estimates used in this memorandum are preliminary.

B.2.3 Evaluation of sensitivity

The sensitivity of the FWM was evaluated by performing separate model runs with each parameter's adjusted value. For example, the model was run 30 times for the 10% change analysis because it was run separately for each of the 29 parameters, including two separate runs for K_{OW}. For parameters with species-specific values (e.g., organism weight), all species values were adjusted simultaneously. The output from each model run was compared with the output from the model run with the initial set of values using the species percent difference (SPD) metric described in FWM Memorandum 2 (Windward 2005). The SPD represents the difference in predicted tissue concentration from the initial predicted concentrations; it was calculated for each species for each model run. Parameter sensitivity was evaluated based on the mean and maximum SPDs.

In addition to the SPD, a relative response ratio was calculated for the plausible range analysis. This metric is calculated as the SPD divided by the percent change in parameter value. This metric allows comparison of parameter responses between the 10% sensitivity analysis and the plausible range analysis because it presents the model response relative to the change in parameter value.

For the 10% sensitivity analysis, results were ranked by maximum SPD, and any parameter with a maximum SPD of 8% or more for any species was selected for inclusion in the uncertainty analysis. The threshold of an 8% change in predicted tissue concentration (for any one species) for a 10% change in parameter value was selected to include parameters to which the model is moderately sensitive. A greater than 1:1 response between parameter value change and model prediction change is generally considered highly sensitive (Arnot 2006).

Also identified were parameters that, when run at the upper or lower end of their plausible range, cause a percentage change that is substantial relative to the change caused by other parameters or relative to the magnitude of change in the input value. In order to select parameters for the uncertainty analysis, results were ranked by maximum SPD, and the distribution of results was evaluated to see if any patterns or break points arose from the results. Parameters were also ranked according to a relative response ratio (SPD divided by percent change in parameter value). This metric can be compared to the 10% sensitivity analysis to see if percent changes in model predictions are the same for small or large changes in parameter values.

B.3 RESULTS OF SENSITIVITY ANALYSES

The results from both sensitivity analyses are discussed in Section 5.0 of the main document. This section presents five results tables. Tables B-3-1 and B-3-2 rank parameters by maximum SPD using results of the 10% sensitivity analysis for target species and for all species, respectively. Tables B-3-3 and B-3-4 rank parameters by maximum SPD using results of the plausible range sensitivity analyses for target species and for all modeled species, respectively. Table B-3-5 ranks parameters by a relative response ratio for the upper- and lower-bound sensitivity analyses for all species. The parameters with a maximum relative response of 0.8 or greater (Table B-5-5) were the same as those with a maximum SPD of 8% or greater presented in Tables B-3-2.

Table B-3-1. Results of the 10 percent sensitivity analysis for predicted fish and crab total PCB concentrations

PARAMETER	MAXIMUM SPD (absolute value)	SPECIES WITH MAXIMUM CHANGE	MINIMUM SPD (absolute value)	MEAN SPD (with negatives)
Dietary absorption efficiency of lipids (alpha)	24%	PSS	10%	-14%
Water content	18%	SC	2%	5%
Lipid density	17%	PSS	10%	13%
Food ingestion rate (G_D)	14%	PS	10%	-12%
Lipid content	14%	PSS	9%	-11%
Dissolved oxygen (DO)	11%	PSS	7%	-9%
Water column temperature	10%	PSS	6%	-8%
Dietary absorption efficiency of NLOM (beta)	9%	DC	6%	-7%
Sediment PCB concentration	8%	SC	8%	-8%
K_{OW}	7%	PSS	4%	-5%
Growth rate constant (k_G)	4%	ES	2%	3%
Sediment organic carbon (OC_{sed})	4%	ES	4%	4%
β (MAF, proportionality constant for sorption capacity of NLOM)	4%	SC	1%	-2%
PCB concentration in porewater	3%	ES	2%	-3%
Organism weight	3%	PSS	2%	-2%
Porewater, fraction ventilated	2%	ES	2%	-2%
Water PCB concentration	2%	SS	2%	-2%
β_{OC} (Proportionality constant for sorption capacity of NLOC)	1.8%	ES	1.2%	1.3%

PARAMETER	MAXIMUM SPD (absolute value)	SPECIES WITH MAXIMUM CHANGE	MINIMUM SPD (absolute value)	MEAN SPD (with negatives)
DOC concentration in water column	0.7%	SS	0.6%	0.6%
D_{DOC} (disequilibrium factor for DOC partitioning)	0.7%	SS	0.6%	0.6%
αDOC (proportionality constant for DOC)	0.7%	SS	0.6%	0.6%
k_M	0.5%	ES	0.2%	0.3%
POC concentration in water column	0.41%	SS	0.32%	0.37%
D_{POC} (disequilibrium factor for POC partitioning)	0.41%	SS	0.32%	0.37%
αPOC (proportionality constant for POC)	0.41%	SS	0.32%	0.37%
A (phytoplankton uptake constant)	0.07%	ES	0.04%	0.05%
B (phytoplankton uptake constant)	0.002%	ES	0.001%	0.001%
Dietary absorption efficiency of water (chi)	0.0003%	DC/SC	0.0002%	-0.0003%
Water density	0.000041%	PSS	0.00001%	-0.00001%

DC – Dungeness crab

ES – English sole

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

Table B-3-2. Results of the 10 percent sensitivity analysis for all species

PARAMETER	MAX SPD	SPECIES WITH MAX CHANGE	MIN SPD	MEAN SPD
Water content	102%	P	2%	19%
Dietary absorption efficiency of lipids (alpha)	-24%	PSS	0%	-9%
Lipid density	-17%	PSS	-1%	11%
Food ingestion rate (G_D)	-14%	PSS	0%	-9%
Lipid content	-14%	PSS	0%	-9%
Dissolved oxygen (DO)	-11%	PSS	0%	-6%
Water PCB concentration	-10%	P/Z	1%	-4%
Water column temperature	-10%	PSS	0%	-6%
Dietary absorption efficiency of NLOM (beta)	-9%	DC	0%	-6%
Sediment PCB concentration	-9%	BI	0%	-6%
K_{OW} -10%	-7%	PSS	3%	-5%
K_{OW}+10%	6%	PSS	2%	4%

PARAMETER	MAX SPD	SPECIES WITH MAX CHANGE	MIN SPD	MEAN SPD
Growth rate constant (kG)	4.3%	ES	0.6%	2.7%
Sediment organic carbon (OC_{sed})	3.9%	ES	0.0%	2.9%
β (MAF, proportionality constant for sorption capacity of NLOM)	-3.7%	SC	0.0%	-1.9%
α_{DOC} (proportionality constant for DOC)	3.5%	P/Z	0.5%	1.3%
DOC concentration in water column	3.5%	P/Z	0.5%	1.3%
D_{DOC} (disequilibrium factor for DOC partitioning)	3.5%	P/Z	0.5%	1.3%
Chemical concentration in porewater	-2.7%	ES	0.0%	-2.0%
Weight	-2.5%	PSS	0.0%	-1.4%
A (phytoplankton/algae uptake constant)	2.5%	P	0.0%	0.4%
Porewater, fraction ventilated	-2.4%	ES	0.0%	-1.8%
POC	2.0%	P/Z	0.3%	0.7%
D_{POC} (disequilibrium factor for POC partitioning)	2.0%	P/Z	0.3%	0.7%
α_{POC} (proportionality constant for POC)	2.0%	P/Z	0.3%	0.7%
β_{OC} (proportionality constant for sorption capacity of NLOC)	1.8%	ES	0.0%	1.1%
K_m	0.5%	ES	0.0%	0.2%
B (phytoplankton/algae uptake constant)	0.05%	P	0.0%	0.01%
Dietary absorption efficiency of water (chi)	-0.0003%	DC/SC	0.0%	-0.0002%
Water density	0.00014%	Z	0.00001%	0.00003%

BI – benthic invertebrate
DC – Dungeness crab
ES – English sole
JF – juvenile fish
P – phytoplankton/algae
PSS – Pacific staghorn sculpin
SC – slender crab
SS – Shiner surfperch
Z – zooplankton

Table B-3-3. Results of the plausible range sensitivity analysis for predicted fish and crab total PCB concentrations

Parameter	Maximum SPD (absolute value)	Species with Maximum Change	Minimum SPD (absolute value)	Mean SPD (with negatives)
Dietary absorption efficiency of lipids (alpha) (upper)	67%	DC	1%	20%
Dietary absorption efficiency of lipids (alpha) (lower)	54%	DC	3%	-19%
Dietary absorption efficiency of NLOM (beta) (lower)	43%	DC	22%	-29%
Sediment PCB concentration (upper)	42%	SC	40%	41%
Sediment PCB concentration (lower)	42%	SC	40%	-41%
Lipid content (upper)	33%	DC	11%	16%
Lipid content (lower)	31%	DC	11%	-16%
Dietary absorption efficiency of NLOM (beta) (upper)	28%	DC	12%	18%
Weight (lower)	25%	DC	16%	-19%
Lipid density (lower)	20%	PSS	12%	15%
Porewater, fraction ventilated (lower)	17%	ES	16%	-17%
Weight (upper)	17%	DC	13%	15%
Lipid density (upper)	15%	PSS	9%	-12%
Temperature (upper)	12%	PSS	8%	10%
Temperature (lower)	12%	PSS	8%	-9%
Water PCB concentration (upper)	11%	SS	9%	10%
β (MAF) upper	11%	SC	3%	6%
β (MAF) lower	11%	SC	4%	-6%
DO (lower)	10%	PSS	6%	-8%
DO (upper)	10%	PSS	6%	8%
Porewater, fraction ventilated (upper)	8%	ES	6%	6%
αDOC (proportionality constant for DOC) (upper)	7%	SS	5%	-6%
K_{OW} (lower)	6%	PSS	3%	-5%
K_{OW} (upper)	6%	PSS	3%	4%
αDOC (proportionality constant for DOC) (lower)	6%	SS	4%	5%
Water PCB concentration (lower)	5%	SS	4%	-5%
αPOC (proportionality constant for POC) (upper)	5%	SS	4%	-4%
Water content (lower)	4%	JF	0%	2%
Water content (upper)	4%	SC	0%	-2%

PARAMETER	MAXIMUM SPD (absolute value)	SPECIES WITH MAXIMUM CHANGE	MINIMUM SPD (absolute value)	MEAN SPD (with negatives)
OC_{sed} (lower)	3%	ES	3%	3%
αPOC (proportionality constant for DOC) (lower)	3%	SS	2%	2%
POC (lower)	2%	SS	2%	2%
OC_{sed} (upper)	1.9%	ES	1.8%	-1.8%
POC (upper)	1.5%	SS	1.2%	-1.4%
DOC (lower)	1.4%	SS	1.0%	1.2%
DOC (upper)	0.91%	SS	0.71%	-0.81%
A (lower)	0.26%	ES	0.15%	0.19%
A (upper)	0.22%	ES	0.13%	-0.16%
B (lower)	0.010%	ES	0.006%	0.008%
B (upper)	0.010%	ES	0.006%	-0.008%
Water density (upper) (seawater)	0.000007%	PSS	0.000001%	0.000002%

DC – Dungeness crab

ES – English sole

JF – juvenile fish

PSS – Pacific staghorn sculpin

SC – slender crab

SS – shiner surfperch

Table B-3-4. Results of the plausible range sensitivity analysis for all species

PARAMETER	MAX SPD	SPECIES WITH MAX CHANGE	MIN SPD	MEAN SPD
Dietary absorption efficiency of lipids (alpha) (upper)	67%	DC	0%	14%
Water PCB concentration (upper)	55%	P/Z	7%	20%
Dietary absorption efficiency of lipids (alpha) (lower)	-54%	DC	0%	-13%
Sediment PCB concentration (upper)	43%	BI	0%	32%
Sediment PCB concentration (lower)	-43%	BI	0%	-32%
Dietary absorption efficiency of NLOM (beta) (lower)	-43%	DC	0%	-23%
α_{DOC} (proportionality constant for DOC) (upper)	-34%	P/Z	-5%	-12%
Lipid content (upper)	33%	DC	1%	15%
Lipid content (lower)	-31%	DC	-1%	-14%
Dietary absorption efficiency of NLOM (beta) (upper)	28%	DC	0%	14%
α_{DOC} (proportionality constant for DOC) (lower)	27%	P/Z	4%	10%
Water PCB concentration (lower)	-25%	P	-3%	-9%
Weight (lower)	-25%	DC	-0%	-15%
α_{POC} (proportionality constant for POC) (upper)	-23%	P/Z	-3%	-8%
Lipid density (lower)	20%	PSS	1%	12%
Porewater, fraction ventilated (lower)	-17%	ES	0%	-13%
Weight (upper)	17%	DC	0%	11%
Water content (upper)	-15%	P	0%	-4%
Lipid density (upper)	-15%	PSS	-1%	-10%
Water content (lower)	14%	P	0%	4%
α_{POC} (proportionality constant for POC) (lower)	13%	P/Z	2%	5%
Temperature water column (upper)	12%	PSS	0%	7%
Temperature water column (lower)	-12%	PSS	0%	-7%
β (MAF, proportionality constant for sorption capacity of NLOM) (upper)	11%	SC	0%	5%
β (MAF, proportionality constant for sorption capacity of NLOM) (lower)	-11%	SC	0%	-5%
Dissolved oxygen (lower)	-10%	PSS	0%	-6%

Parameter	Max SPD	Species with Max Change	Min SPD	Mean SPD
Dissolved oxygen (upper)	10%	PSS	0%	6%
POC (lower)	10%	P/Z	1%	3%
A (phytoplankton/algae uptake constant) (lower)	9%	P/Z	0%	1%
Porewater, fraction ventilated (upper)	8%	ES	0%	5%
A (phytoplankton/algae uptake constant) (upper)	-8%	P/Z	0%	-1%
POC (upper)	-8%	P/Z	-1%	-3%
DOC (lower)	7%	P/Z	1%	2%
K_{OW} (lower)	-6%	PSS	-2%	-4%
K_{OW} (upper)	6%	PSS	2%	4%
DOC (upper)	-4%	P/Z	-1%	-2%
OC_{sed} (lower)	3%	ES	0%	2%
OC_{sed} (upper)	-2%	ES	0%	-1%
B (phytoplankton/algae uptake constant) (lower)	0.36%	P	0.01%	0.06%
B (phytoplankton/algae uptake constant) (upper)	-0.36%	P	-0.01%	-0.06%
Water density (upper) (seawater)	-0.00003%	Z	-0.00000%	-0.00001%

Table B-3-5. Relative response ratio for upper and lower bound sensitivity analyses for all species

Parameter	Relative Response		Response to Changes in Input Values			% Change in Parameter Input Values	
	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
Water content (lower)	-15.6	-2.1	14%	P	4%	-2%	-0.9%
Water content (upper)	-15.0	-2.5	-15%	P	-4%	2%	1.0%
Dietary absorption efficiency of Lipids (alpha) (upper)	2.4	0.6	67%	DC	14%	23%	28%
Lipid density (lower)	-1.8	-1.1	20%	PSS	12%	-11%	
Lipid density (upper)	-1.4	-0.9	-15%	PSS	-10%	11%	
Dissolved Oxygen (DO) (upper)	1.1	0.7	10%	PSS	6%	9%	
Dissolved Oxygen (DO) (lower)	1.1	0.7	-10%	PSS	-6%	-9%	
Water column temperature (upper)	1.1	0.6	12%	PSS	7%	11%	
Water PCB concentration (upper)	1.0	0.4	55%	P/Z	20%	55%	
Dietary absorption efficiency of NLOM (beta) (upper)	1.0	0.8	28%	DC	14%	17%	28%

Parameter	Relative Response		Response to Changes in Input Values			% Change in Parameter Input Values	
	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
Water PCB concentration (lower)	1.0	0.4	-25%	P	-9%	-25%	
Water column temperature (lower)	1.0	0.6	-12%	PSS	-7%	-12%	
Sediment PCB concentration (lower)	0.9	0.6	-43%	BI	-32%	-50%	
Sediment PCB concentration (upper)	0.9	0.6	43%	BI	32%	50%	
Lipid content (upper)	0.9	0.9	33%	DC	15%	18%	39%
Lipid content (lower)	0.8	0.9	-31%	DC	-14%	-16%	-39%
K_{OW} (lower)	0.7	0.5	-6%	PSS	-4%	-9%	
Dietary absorption efficiency of Lipids (alpha) (lower)	0.7	0.3	-54%	DC	-13%	-52%	-80%
K_{OW} (upper)	0.6	0.4	6%	PSS	4%	10%	
Dietary absorption efficiency of NLOM (beta) (lower)	0.5	0.6	-43%	DC	-23%	-36%	-80%
αDOC (proportionality constant for DOC) (lower)	-0.4	-0.2	27%	P/Z	10%	-63%	
β (MAF - proportionality constant for sorption capacity of NLOM) (lower)	0.4	0.2	-11%	SC	-5%	-29%	
β (MAF - proportionality constant for sorption capacity of NLOM) (upper)	0.4	0.2	11%	SC	5%	29%	
DOC (lower)	-0.4	-0.1	7%	P/Z	2%	-18%	
OCsed (lower)	-0.4	-0.3	3%	ES	2%	-8%	
OCsed (upper)	-0.4	-0.2	-2%	ES	-1%	6%	
Porewater, fraction ventilated (lower)	0.3	0.2	-17%	ES	-13%	-55%	-50%
Weight (lower)	0.3	0.5	-25%	DC	-15%	-29%	-77%
Weight (upper)	0.3	0.2	17%	DC	11%	57%	55%
DOC (upper)	-0.3	-0.1	-4%	P/Z	-2%	14%	
A (phytoplankton/ algae uptake constant) (lower)	0.3	0.03	9%	P/Z	1%	33%	
A (phytoplankton/ algae uptake constant) (upper)	0.24	0.03	-8%	P/Z	-1%	-33%	

Parameter	Relative Response		Response to Changes in Input Values			% Change in Parameter Input Values	
	Maximum[a]	Mean[b]	Maximum SPD	Species with Maximum SPD	Mean SPD	Mean	Maximum[c]
α_{DOC} (proportionality constant for DOC) (upper)	-0.23	-0.08	-34%	P/Z	-12%	150%	
POC (lower)	-0.22	-0.07	10%	P/Z	3%	-45%	
α_{POC} (proportionality constant for POC) (lower)	-0.22	-0.08	13%	P/Z	5%	-60%	
POC (upper)	-0.19	-0.07	-8%	P/Z	-3%	41%	
α_{POC} (proportionality constant for POC) (upper)	-0.15	-0.05	-23%	P/Z	-8%	149%	
Porewater, fraction ventilated (upper)	0.08	0.07	8%	ES	5%	75%	100%
B (phytoplankton/ algae uptake constant) (upper)	-0.01	-0.001	-0.36%	P	-0.06%	67%	
B (phytoplankton/ algae uptake constant) (lower)	-0.01	-0.001	0.36%	P	0.06%	-67%	
Water density (upper) (seawater)	0.00002	-0.00001	0.00003%	Z	-0.00001 %	2%	

[a] Calculated as the maximum species percent difference divided by the mean or maximum percent change in parameter value. Maximum percent change is used for species-specific parameters only.

[b] Calculated as the mean species percent difference divided by the mean percent change in parameter value.

[c] Percent change for species-specific parameters only.

BI – benthic invertebrate

DC – Dungeness crab

ES – English sole

JF – juvenile fish

P – phytoplankton/algae

PSS – Pacific staghorn sculpin

SC – slender crab

SS – Shiner surfperch

Z – zooplankton

Based on the 10% sensitivity analysis, all parameters that had a maximum SPD equal to or greater than 8% were selected for inclusion in the uncertainty analysis (Tables B-3-1, B-3-2). K_{OW} was selected for inclusion in the uncertainty analysis because it was close to the 8% threshold (7% SPD for Pacific staghorn sculpin) and because it is a key chemical-specific parameter with uncertainty. The food ingestion rate (G_D) with a maximum SPD of 14% will not be included in the uncertainty analysis because it is calculated by an equation within the model, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0), cannot test parameters defined by equations.

A 10% change in predicted tissue concentrations was considered sufficient to warrant inclusion in the uncertainty analysis. When maximum SPDs of the plausible range analysis were ranked for target species, 11 parameters were selected for inclusion in the uncertainty analysis. When maximum SPDs of the plausible range analysis were ranked for all species (Table B-3-4), three additional parameters had maximum SPDs of 10% or greater (water column PCB concentration, α_{DOC}, and α_{POC}). α_{DOC}, and α_{POC} were not included in the uncertainty analysis because they are constants within equations in the model rather than true input parameters, and Crystal Ball®, the software used to run the Monte Carlo uncertainty analysis (Section 6.0) cannot test parameters within equations. The phytoplankton uptake constant (A) was included in the uncertainty analysis based on advice from Jon Arnot (2005). A complete discussion of sensitivity analysis results is presented in the main document.

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Appendix C. Assignment of Parameter Distributions and Correlations for Uncertainty Analysis

Appendix C. Assignment of Parameter Distributions and Correlations for Uncertainty Analysis

As discussed in the Food Web Model (FWM) Memorandum 2 (Windward 2005), a probabilistic approach was employed to investigate model uncertainty. Specifically, Monte Carlo simulation was used to investigate the effects of parameter variability and uncertainty on model predictions. As described in Section 5.0 and Appendix B, sensitivity analyses were conducted to identify sensitive parameters. Because these parameters most affect model output, they were further investigated in the uncertainty analysis, as described in this appendix.

Distributions, rather than point estimates, were assigned for input parameters as appropriate (i.e., if data are available and the FWM is sensitive to a given parameter). In the Monte Carlo simulations, the FWM was run 10,000 times using Decisioneering® Crystal Ball 7® software. During each model iteration, different combinations of values for each input parameter were selected based on the probability distribution for each parameter. Output from this uncertainty analysis are distributions of the relative probability of predicted tissue concentrations for each species based on the distributions of FWM input parameter values. In addition to assigning distributions for parameters, correlations may also be defined to prevent improbable combinations of parameter values, such as the combination of an extremely high organism lipid content and an extremely high organism water content.

This appendix describes the process by which distributions were selected for parameters to which the model is sensitive, the assignment of distributions for these parameters, and the assignment of correlations between parameters.

C.1 Approach for Development of Parameter Distributions

As described in Section 6.2.1, the first step of developing the Monte Carlo version of the model is development of parameter distributions. Only parameters identified as sensitive in the sensitivity analysis were included in the uncertainty analysis. The following approach was used to develop parameter distributions:

1) When site-specific data were available, the distribution was determined through statistical analysis of the data.[1] Normal distributions were defined in Crystal Ball® by their mean and standard deviation and truncated at zero (with no upper-bound truncation). For non-parametric datasets, a custom

[1] Distributions were evaluated using ProUCL software (EPA 2004). The distribution that the software determined to best fit the data was selected for use in Monte Carlo simulations.

distribution was assigned based directly on site-specific empirical data.[2] Crystal Ball® randomly selects parameter values from the empirical data for each model iteration.

2) A normal or lognormal distribution was assigned if the parameter was biological in nature and/or empirical data for similar parameters exhibited a normal or lognormal distribution (e.g., all other LDW fish species analyzed had normal lipid distributions, so juvenile fish were assigned a normal distribution in the absence of empirical LDW juvenile fish lipid data). The mean and standard deviation of the distributions of parameters from the literature were based on published data when possible.

3) For parameters with insufficient data to define a distribution, and/or available data did not conform to a normal or lognormal distribution, a triangle distribution was assigned (MacIntosh et al. 1994). The mode of the triangle was defined as the mean of the data if the data were considered sufficiently relevant and comprehensive. For more uncertain data, the mode was based on consideration of published selections for parameter values used in other food web models (Arnot and Gobas 2004; Gobas and Arnot 2005). The tails of the triangle were defined by the literature values if they were considered sufficient to bound a plausible range.

C.2 Development of Parameter Distributions

Distributions define the frequency for which certain parameter values will be used in the multiple iterations of the model. Distributions were developed for the majority of the parameters to which the model was found to be sensitive (Section 5.0 and Appendix B). Distributions were developed by species for species-specific parameters (e.g., Dungeness crab weight, slender crab weight). This section details the decision process for development of parameter distributions, including application of the above approach based on available data and professional judgment.

C.2.1 Sensitive parameters without distributions

Distributions were not developed for eight of the parameters to which the model is sensitive. Four parameters investigated in the sensitivity analysis are calculated by the model. Thus, they could not be varied in an automated manner in the Monte Carlo version of the model and were not included in the uncertainty analysis. These parameters were growth rate, freely dissolved chemical concentration in porewater, the proportionality constant describing similarity in phase partitioning of dissolved

[2] In the custom distributions used in this assessment, Crystal Ball draws randomly from empirical data. For example, the organism weights for shiner surfperch were assigned a custom distribution because the data were non-parametric. During model iterations, Crystal Ball chooses a value randomly from the 458 empirical values that define the custom distribution (Table C-2-1).

organic carbon (DOC) relative to that of octanol (α_{DOC}), and the proportionality constant describing similarity in phase partitioning of particulate organic carbon (POC) relative to that of octanol (α_{POC}).

Four of the parameters to which the model was found to be sensitive were species dietary absorption efficiencies of lipids for fish (for three fish species and juvenile fish). No distributions were assigned for fish dietary absorption efficiency of lipids because the range of empirical values was too small to define a distribution.

C.2.2 Sensitive parameters for which distributions were developed

Distributions were developed for the remaining 45 parameters identified in the sensitivity analysis and are presented in Table C-2-1. The following sections describe the development of distributions for these parameters, which was dependent on available data for each parameter and consistent with the approaches described in Section C.1.

Table C-2-1. Uncertainty analysis input values

PARAMETER DESCRIPTION	UNITS	DISTRIBUTION TYPE	DISTRIBUTION VALUES	CORRELATION COEFFICIENT	SOURCE/NOTES
Environmental Parameters					
Total concentration of PCBs in the water column	ng/L	normal	Mean = 2, SD = 0.4	id	King County water data (2005),, standard deviation was selected to include range of empirical data..
Concentration of particulate organic carbon (POC) in the water column	kg/L	normal	mean = 2.9×10^{-7}, SD = 6.3×10^{-8}	with water temperature = 0.0087; with dissolved oxygen = 0.23	Unpublished King County 2005 water data (Mickelson 2006); used standard error from raw data as standard deviation for distribution of estimates of the mean. POC is calculated based on TOC and DOC as described in Appendix A, Table A-2-1. Correlation based on individual samples from 2 locations taken on 10 occasions.
Mean water column temperature	°C	normal	mean = 11.6, SD = 0.0678	with POC = 0.0087; with dissolved oxygen = -0.34	Unpublished King County 2005 water (Mickelson 2006); used standard error from raw data as standard deviation for distribution of estimates of the mean. . Correlation based on individual samples from 2 locations taken on 10 occasions.
Dissolved oxygen concentration in the water column	mg/L	normal	mean = 8.0, SD = 0.36	with POC = 0.0087; with water temperature = -0.34	Unpublished King County 2005 water data (Mickelson 2006); used standard error from raw data as standard deviation for distribution of estimates of the mean. . Correlation based on individual samples from 2 locations taken on 10 occasions.
Concentration of PCBs in sediment	µg/kg dw	normal	mean = 250, SD = 64		SWAC developed from Phase 1 and 2 data as described in Appendix A, section A.2. Standard deviation calculated as described in Appendix C, section C.2.1.2.

Table C-2-1, cont.

Parameter Description	Units	Distribution Type	Distribution Values	Correlation Coefficient	Source/Notes
Chemical Parameters					
Octanol-water partition coefficient for PCBs (log K_{OW})	unitless	normal	Mean = 6.62, SD = 0.186	na	K_{OW}s for each congener from Hawker and Connell (1988); used standard error from raw data as standard deviation for distribution of estimates of the mean.
Biological Parameters					
Proportionality constant expressing the sorption capacity of NLOM relative to that of octanol (β or MAF)	unitless	normal	mean = 0.035, SD = 0.005	na	Mean from Arnot and Gobas (2004); SD from Arnot (2005).
Resistance to chemical uptake through aqueous phase for phytoplankton/algae (A)	day^{-1}	normal	mean = 6×10^{-5}, SD = 1×10^{-5}	na	Gobas and Arnot (2005)
Density of lipids	kg/L	triangle	mode = 0.9, min = 0.8, max = 1		Arnot (2006)
Phytoplankton					
Lipid content of organism	%	normal	mean = 0.12, SD = 0.05	id	Mackintosh et al. (2004)
Water content of organism	%	normal	mean = 95.6, SD = 0.55	id	Mackintosh et al. (2004); SD selected to include range in Mackintosh et al. (2004).
Zooplankton					
Organism weight	kg	normal	mean = 1.6×10^{-7}, SD = 3.6×10^{-8}	id	Giles and Cordell (1998); SD selected to include range in Giles and Cordell (1998).
Lipid content	%	normal	mean = 1.2, SD = 0.3	id	Kuroshima et al. (1987); SD selected to include range in Kuroshima et al. (1987).
Water content of organism	%	normal	mean = 90, SD = 1.5	id	Kuroshima et al. (1987); SD selected to include range in Kuroshima et al. (1987).
Dietary absorption efficiency of lipids (alpha)	%	triangle	mode = 72, min = 55, max = 85	id	Arnot and Gobas (2004)

Table C-2-1, cont.

Parameter Description	Units	Distribution Type	Distribution Values	Correlation Coefficient	Source/Notes
Dietary absorption efficiency of NLOM (beta)	%	triangle	mode = 72, min = 55, max = 85	id	Arnot and Gobas (2004)
Benthic Invertebrates					
Organism weight	kg	custom[a]	mean = 5.1 x 10^{-5}, raw data	id	LDWG Phase 2 data (n = 10); average from each sample location.
Lipid content	%	normal	mean = 0.89, SD = 0.26	with water content = -0.57	LDWG Phase 2 data.
Water content of organism	%	normal	mean = 88.9, SD = 3.6	with lipid content = -0.57	LDWG Phase 2 data.
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.2, min = 0.05, max = 0.25	id	Winsor et al. (1990)
Dietary absorption efficiency of lipids (alpha)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)
Dietary absorption efficiency of NLOM (beta)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)
Juvenile Fish					
Organism weight	kg	normal	mean = 6 x 10^{-3}, SD = 7 x 10^{-4}	id	Derived from all Phase 2 (2004 and 2005) individual ≤ 80 mm shiner surfperch specimens from the LDW and background locations.
Lipid content	%	normal	mean = 2.5, SD = 0.6	id	LDWG Phase 2 data
Water content of organism	%	normal	mean = 73.9, SD = 2.0	id	LDWG Phase 2 data
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.01, min = 0.005, max = 0.02	id	Gobas and Wilcockson (2003); Gobas and Arnot (2005)
Dietary absorption efficiency of NLOM (beta)	%	normal	mean = 60, SD = 3	id	Arnot and Gobas (2004)

Table C-2-1, cont.

Parameter Description	Units	Distribution Type	Distribution Values	Correlation Coefficient	Source/Notes
Slender Crab					
Organism weight	kg	normal	mean = 0.164, SD = 0.0318	id	LDWG Phase 2 data.
Lipid content	%	custom[a]	mean = 1.1, raw data	with water content = 0.6	LDWG Phase 2 data (n = 5).
Water content of organism	%	normal	mean = 83.6, SD = 1.19	with lipid content = 0.6	LDWG Phase 2 data.
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.02, min = 0.01, max = 0.03	id	Gobas and Wilcockson (2003); Gobas and Arnot (2005); Winsor et al. (1990)
Dietary absorption efficiency of lipids (alpha)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)
Dietary absorption efficiency of NLOM (beta)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)
Dungeness Crab					
Organism weight	kg	custom[a]	mean = 0.423, raw data	id	LDWG Phase 2 data (n = 51).
Lipid content	%	normal	mean = 2.6, SD = 1.4	with water content = -0.93	LDWG Phase 1 and 2 data.
Water content of organism	%	normal	mean = 82, SD = 2.9	with lipid content = -0.93	LDWG Phase 1 and 2 data.
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.02, min = 0.01, max = 0.03	id	Gobas and Wilcockson (2003); Gobas and Arnot (2005); Winsor et al. (1990)
Dietary absorption efficiency of lipids (alpha)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)
Dietary absorption efficiency of NLOM (beta)	%	triangle	mode = 75, min = 15, max = 96	id	Arnot and Gobas (2004)

Table C-2-1, cont.

Parameter Description	Units	Distribution Type	Distribution Values	Correlation Coefficient	Source/Notes
Pacific Staghorn Sculpin					
Organism weight	kg	custom[a]	mean = 0.060, raw data	id	LDWG Phase 2 data (n = 272).
Lipid content	%	normal	mean = 2.1, SD = 0.37	with water content = -0.80	LDWG Phase 2 data.
Water content of organism	%	normal	mean = 79.0, SD = 0.602	with lipid content = -0.80	LDWG Phase 2 data.
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.05, min = 0.02, max = 0.1	id	
All fish dietary absorption efficiency of NLOM (beta)	%	normal	mean = 60, SD = 3	id	Arnot and Gobas (2004)
Shiner Surfperch					
Organism weight	kg	custom[a]	mean = 0.017, raw data	id	LDWG Phase 2 data (n = 458).
Lipid content	%	normal	mean = 4.6, SD = 1.4	with water content = -0.83	LDWG Phase 1 and 2 data.
Water content of organism	%	normal	mean = 73.9, SD = 2.03	with lipid content = -0.83	LDWG Phase 2 data.
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.01, min = 0.005, max = 0.02	id	Gobas and Wilcockson (2003); Gobas and Arnot (2005)
All fish dietary absorption efficiency of NLOM (beta)	%	normal	mean = 60, SD = 3	id	Arnot and Gobas (2004)
English Sole					
Organism weight	kg	custom[a]	mean = 0.198, raw data		LDWG Phase 2 data (n = 245).
Lipid content	%	normal	mean = 5.5, SD = 1.3	with water content = -0.76	LDWG Phase 2 data.
Water content of organism	%	normal	mean = 75.0, SD = 1.77	with lipid content = -0.76	LDWG Phase 2 data.

Table C-2-1, cont.

PARAMETER DESCRIPTION	UNITS	DISTRIBUTION TYPE	DISTRIBUTION VALUES	CORRELATION COEFFICIENT	SOURCE/NOTES
Relative fraction of porewater ventilated	unitless	triangle	mode = 0.1, min = 0.005, max = 0.2	id	Gobas and Wilcockson (2003); Gobas and Arnot (2005)
All fish dietary absorption efficiency of NLOM (beta)	%	normal	mean = 60, SD = 3	id	Arnot and Gobas (2004)

SD – standard deviation

[a] In the custom distributions used in this assessment, Crystal Ball® draws randomly from empirical data. During model iterations, Crystal Ball® chooses a value randomly from the empirical values that define the custom distribution.

id – inadequate data to evaluate correlations

na – not applicable; no expected correlations with other parameters with distributions

C.2.2.1 Biological parameters

There were two non-species-specific biological parameters to which the model was found to be sensitive. Both the proportionality constant expressing the sorption capacity of non-lipid organic matter relative to that of octanol (β) and the resistance to chemical uptake through the aqueous phase for phytoplankton/algae (A) were assigned normal distributions. These distributions and their means and standard deviations were based on published models, modeling reports and personal communication with Jon Arnot (Arnot 2005; Arnot and Gobas 2004; Gobas and Arnot 2005).

The majority of site-specific, species-specific lipid content and water content data were normally distributed. Thus, normal distributions based on empirical data were assigned for most of these parameters. One exception was slender crab lipid content, which had a non-parametric distribution. A custom distribution was assigned for this parameter. For species without site-specific water content and lipid data, parameter distributions were assumed to be normal.

For some species, empirical weight data were normally distributed; thus, these weight parameters were assigned normal distributions. For other species, distributions of weight data were not normal or lognormal. This may have occurred because only organisms of a minimum size were targeted during sampling. For species with weight distributions that were not normal or lognormal, custom distributions were assigned.

Few data were available for dietary absorption efficiencies of lipids and NLOM, density of lipids, and for ventilation of porewater. Lacking empirical data to describe distributions, the ranges for these parameters developed for the sensitivity analysis (Section 5.0 and Appendix B) were used for the uncertainty analysis. These ranges were primarily from Arnot and Gobas (2004). For crabs, benthic invertebrates, phytoplankton, and zooplankton, triangle distributions were assigned for dietary absorption efficiencies of lipids and NLOM because the available values from the literature were not consistent with normal or lognormal distributions (e.g., the minimum value was four times lower than the mean, while the maximum was only 25% higher than the mean). Similarly, the fractions of porewater ventilated for all species were assigned triangle distributions. Density of lipids was also assigned a triangle distribution with the same range as used in the sensitivity analysis and as recommended by Jon Arnot (2006). The dietary absorption of NLOM for fish was assigned a normal distribution consistent with the range used in the sensitivity analysis.

C.2.1.2 Environmental and Chemical Parameters

The concentration of POC in the water column, the mean water column temperature, and the dissolved oxygen concentration in the water column were all assigned normal distributions. Because estimates of the mean are normally distributed (central limit theorem), a normal distribution was assigned for these parameters. The standard error of the original distribution can be used to define a confidence interval on the mean, similar to the way a standard deviation may be used to define a confidence interval for normally distributed data. Thus, the standard error of the empirical data was used as the standard deviation of the distribution of the estimates of the mean.

Fewer empirical data were available for concentration of PCBs in water than for conventional water parameters such as temperature, and dissolved oxygen. Because the mean PCB water concentration was of interest, a normal distribution was assigned. A standard deviation was selected to include the range of empirical data.

The mean of log K_{OW} was of interest because the model uses only one K_{OW} for all model calculations for all species. Thus, the average of available data across species was most appropriate. A normal distribution was assigned for the range of estimates of the mean, with a standard deviation equal to the standard error of the estimated of site specific K_{OW} data (described in Section A.2.6)

The total PCB concentration in sediment was also assigned a normal distribution because it is the distribution of estimates of the mean that are of interest. This is again based on the central limit theorem, which states that estimates of the mean are normally distributed. The standard deviation was selected to describe a 95% confidence interval of the range selected for the sensitivity analysis (125 μg/kg dw as 5th percentile and 375 μg/kg dw as 95th percentile, Section B.2.2).

C.3. APPROACH AND ASSIGNMENT OF PARAMETER CORRELATIONS

Correlations were assigned between some of the parameters for which distributions were developed to prevent improbable combinations of values for related parameters. To evaluate correlations, data must be available that can be reasonably matched (in time and location, or by sample specimens) and must be similarly robust in terms of number of samples and data quality. For parameter pairs expected to be correlated for biological or environmental reasons, a correlation test was performed if possible. The calculated correlation coefficients were then included and applied to both parameters in the Monte Carlo model.

Table C-2-1 identifies the parameters found to be correlated and the magnitude of correlation. For many of the uncertain parameters for which correlations were biologically plausible, insufficient data were available to assess correlation (e.g., weight data were collected for each organism, but lipid data were based on composite samples). All parameters for which correlation might be plausible, but for which data were insufficient to evaluate correlations, are noted in Table C-2-1 in the correlation column. Correlation was assessed for several water quality parameters (i.e., POC, mean water temperature, and dissolved oxygen concentration in the water column), and correlation coefficients were included in the model.

For biological parameters, correlations could be assessed only for water and lipid contents for fish, crabs, and benthic invertebrates. Correlations between water and lipid contents were primarily negative, as expected. One exception was slender crab, which exhibited a positive correlation between water and lipid contents. Slender crab lipid and water content data for the model are presented as "whole-body" crabs, but these data are actually calculated based on edible meat and hepatopancreas composite samples (for more detailed description, see Appendix A, Section A.2.3). Correlations for slender crab edible meat lipid and water contents and for hepatopancreas lipid and water contents were also found to be positive, although the sample sizes were small (edible meat n = 13, hepatopancreas n = 5).

C.4 REFERENCES

EPA. 2004. ProUCL Version 3.0. Statistical software to compute Upper Confidence Limits of the unknown population mean [online]. Technical Support Center for Monitoring and Site Characterization US Environmental Protection Agency. Updated 5/6/2004. Available from: http://www.epa.gov/nerlesd1/tsc/download.htm.